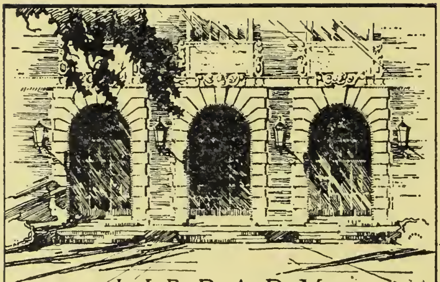

THE
COLLIERY MANAGER'S
HANDBOOK

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COLLIERY MANAGER'S HANDBOOK

A COMPREHENSIVE TREATISE ON THE LAYING-OUT AND WORKING OF COLLIERIES

DESIGNED AS

A BOOK OF REFERENCE FOR COLLIERY MANAGERS

AND

FOR THE USE OF COAL-MINING STUDENTS PREPARING FOR FIRST-CLASS CERTIFICATES

BY

CALEB PAMELY

MINING ENGINEER AND SURVEYOR, MEMBER OF THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS, AND MEMBER OF THE SOUTH WALES INSTITUTE OF MINING ENGINEERS

With nearly 500 Plans, Diagrams, and other Illustrations

Capio Lumen

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PREFACE.

Even a slight acquaintance with the duties and responsibilities of a Colliery Manager will lead to the conclusion that he had need be almost omniscient within his own province. Besides his responsibility for satisfactory results in the opening-out and working of a colliery, under the ever-varying conditions of coal-mining enterprise, there rests upon him a heavy legal as well as moral responsibility which no true man would wish to shirk, and in the discharge of which he has to prepare for that which happens more often, perhaps, in his career than in that of most professional men—viz., *the unexpected.* It becomes him, therefore, to fit himself beforehand in every possible way for the discharge of his onerous duties. In so doing he will have to acquire the rudiments of Geology, Chemistry, and Electrical Engineering; a good deal more than the rudiments of Mechanical Engineering, Surveying, and Plan-making; and to make himself master of the mysteries comprised in the comprehensive terms Practical Mining and Ventilation. Further, he must be thoroughly versed in the obligations imposed upon him and his subordinates by the Acts of Parliament bearing on the subject of Coal Mining, and by the Special Rules in force in any given district.

The Author is well aware, after twenty years' experience, that the best and indeed the only satisfactory preparation for the efficient discharge of the duties of the Colliery Manager is that which is to be gained in the laborious school of experience; but he knows also that the wise use of a carefully prepared and comprehensive handbook—such as he ventures to believe the volume now in the reader's hand will be found to be—would have been to him an incalculable boon in the earlier years of his course, and hardly less so subsequently as a book

of reference and of practical guidance. No doubt excellent handbooks already exist, dealing with various branches of the subject; but the Author's aim has been in the following pages to prepare a work more complete in itself than any of its predecessors, and one comprising the most recent information as to the ever-progressing science and art of Coal Mining. In the use of the work by students, it is believed that the questions and answers given on the various subjects will be found specially helpful.

The Author gratefully acknowledges the assistance which has been given him in preparing this work for the press by his friends Mr. J. T. Robson, H. M.'s Inspector of Mines for South Wales, and the Rev. J. E. Flower, M.A., of Wandsworth; and also the courtesy shown by the Council of the Mining Institute of Scotland in granting him permission to quote the result of their Commission of Mining Engineers, as given in their *Transactions* (vol. iii., pp. 51 to 124). Besides much valuable information which has been obtained from the *Transactions* of the North of England and South Wales Institutes of Mining Engineers, he has also received considerable assistance from the columns of the *Practical Engineer* and the *Colliery Guardian*, and from other sources, reference to which will be found in various pages of the work.

The greatest care has been taken to ensure accuracy in every respect, but if any mistake has escaped notice the Author will be thankful to have it pointed out to him.

The preparation of this handbook—which for several years has occupied such time as the writer has been able to give to it—has been to him a most congenial task; and he ventures, in sending it forth, to express the hope that the work may be found as useful to the student, and to those engaged in the management of collieries, as the preparation of it has been pleasant and profitable to himself.

PONTYPRIDD,
January, 1891.

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THE

COLLIERY MANAGER'S HAND-BOOK.

CHAPTER I.

GEOLOGY.

Stratified and Unstratified Rocks—Dip—Rise—Outcrop—Strike—Diversified arrangement of Rocks—Faults—Classification of the Rocks into Systems—Igneous Rocks—Description of the different systems of Stratified Rocks.

The Science of Geology in its widest sense comprises all that is known or can be ascertained as to the constitution and history of our globe. It has been the life-study of many eminent men, and as one of the youngest of the sciences has made amazing progress; but our knowledge is still limited to within a mile or two of the surface and there is room for much speculation as to the interior to which we have no hope of penetrating.

An examination of the rocks soon led to their being divided into *stratified* and *unstratified*. The former have the appearance of having been deposited in layers one above another, and that unquestionably by aqueous action. *Unstratified*

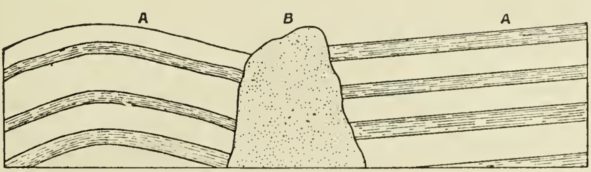


Fig. 1.—Stratified and Unstratified Rocks.
A A Stratified, and B Unstratified.

rocks are those which appear in amorphous masses and exhibit no such signs. Granite is a specimen of these rocks. Some scientists are of opinion that at one time the world was entirely in a state of fusion, and that even now the inner portion is in this condition, the outer crust only having as yet cooled. This crust in cooling became a hard unstratified mass, most part of which is granite. In process of time the waters began to deposit layer after layer of other material, the first layers being imperfectly stratified and called the metamorphic rocks, because formed partly by water and partly by fire. Then followed the other deposits, layer after layer through countless ages till the earth's crust was as we have it now. The rock beds were not always deposited on horizontal surfaces, and the result of deposition on an inclined surface would be to form a bed at the same angle as the surface on which it was deposited. As beds were deposited

over extensive areas there may have been many variations of surface causing the beds to be inclined at different angles and in different directions. In cases where beds were originally deposited in a horizontal position, subsequent volcanic disturbances have frequently changed this into an inclined one.

In the earliest of the aqueous rocks signs of vegetable and animal life are found beginning with the lowest type. As they died, the waters covered them, depositing again other layers of sand and clay. In course of time the waters receded and fresh forms of life appeared, to be themselves buried in their turn; each form, whether of animal or vegetable, rising to a higher state of perfection with each layer.

The great fact to be remembered in regard to these stratified rocks is, that they have been deposited in regular order all the world over and that each has its characteristic fossils. Not that every formation of rock was deposited all over the world, but that the order of finding them, if there, remains generally the same. Sometimes, indeed, a formation is altogether wanting, or the order of their

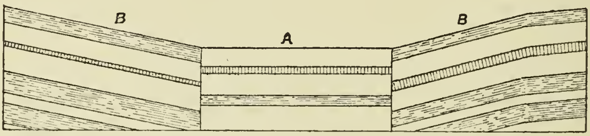


Fig. 2.—Horizontal and Inclined Strata.
A Horizontal, B B Inclined.

position reversed, but these are exceptions and can usually be accounted for by denudation or volcanic agency.

The angle at which a stratum inclines to the horizon is called its *dip* when viewed in the direction of the fall, and the *rise* when viewed in the contrary direction. When an inclined stratum comes to the surface its edge is called the *outcrop*, and the line of outcrop along a level surface is termed its *strike*.

The dip is always at right angles to the strike, so that if the dip be given, the

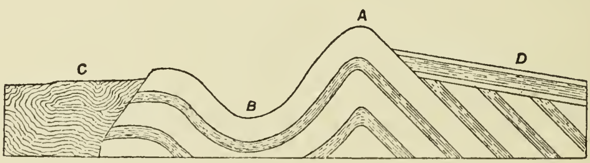


Fig. 3.—Unconformable, Bent, and Contorted Strata.

strike is also known; but if the strike only be given, the dip cannot be known from it, because the dip may incline to either side of the strike. When strata dip in opposite directions from a ridge or line of elevations the axis is termed *anticlinal* or *saddleback* as at A, Fig. 3, and when they dip towards a common line of depression as at B, the axis is said to be *synclinal*, and the depression so formed is spoken of as a *trough* or *basin*. When bent and twisted they are termed *contorted* as at C. When strata lie upon each other in parallel order as at D, they are said to be *conformable*; but when one set reclines upon another at a different angle they are termed *unconformable*. The strata are said to be *monoclinal* when, though lying at different angles, they all slope the same way; *periclinal* when dipping in every direction from a common centre. When strata terminate abruptly in a bold bluff edge, they are said to form an *escarpment*.

The dislocations, fractures, and fissures produced in the rocky crust by volcanic

agency are known by such terms as *faults, slips, hitches, heaves, leaps, throws, troubles, &c.*

Faults may be so thin as to be easily mistaken for the ordinary jointing of the rocks they traverse. More often, however, there is a considerable space between their "walls" or "cheeks." This space is sometimes filled up with *débris* from the adjoining rocks, or with matters deposited from the solutions circulating within them. At others the space is filled with strings or pockets of iron pyrites, oxide of iron, and other metallic substances, together with quartz, clay, &c. When filled up with injections or infiltrations of mineral matter, the dislocations are spoken of as *dykes, lodes,* and *veins.*

These disturbances contain carbonaceous matters where they traverse the coal measures, which may at times be accompanied by metallic minerals. There is no essential difference between faults found in the coal-measures and the mineral veins ("fissure veins") of a metalliferous district. For instance, the great Minerva lead lode is, throughout a part of its course, the chief fault of the Denbighshire coal-field.

The displacement in faults is not necessarily caused at one time; there is frequently clear evidence of repeated movement.

They may occur in groups of two or three, with parallel or nearly parallel bearings, sometimes all dipping in the same direction, but usually two sets dip in opposite directions. There is often connected with these groups another series at right angles to them of a somewhat later origin.

A division of the stratified rocks has been made according to their fossils or the types of life they exhibit as compared with our present orders of life:—

CAINOZOIC OR TERTIARY	Post-tertiary. Tertiary.
MESOZOIC OR SECONDARY	Cretaceous. Oolitic. Triassic.
PALÆOZOIC OR PRIMARY	Permian. Carboniferous. Devonian. Silurian. Cambrian. Laurentian.
AZOIC	Metamorphic.

The igneous rocks are divided into

AZOIC	1. Granitic Rocks. 2. Trappean Rocks. 3. Volcanic Rocks.

The study of the igneous rocks is attended with much difficulty. Their composition is somewhat complex, and often two rocks having the same composition present a totally different appearance owing to the fact that they were cooled under different circumstances. They have no order of superposition, but have been erupted from below, and are found traversing the stratified rocks in veins. Moreover they contain no organic remains by which their relative ages can be satisfactorily established. The igneous rocks contain many valuable minerals, building stone, &c.

The METAMORPHIC SYSTEM is the lowest of the stratified rocks. In it no signs of organic remains have yet been discovered, and by some it is held that these rocks never contained fossils; that the epoch of their deposition was previous to the creation of animal or vegetable life on the earth, and hence the meta-

morphic period is classed with the igneous rocks as Azoic (destitute of life). Many, again, think that the signs of life have been obliterated or, perhaps, not yet discovered, and prefer the term Hypozoic (below life). The Metamorphic is very productive in a mercantile point of view, yielding marble, slates, serpentines, quartz; metallic veins of copper, lead and tin frequently traverse the beds of the system. Gold and silver and many precious stones are among the valuables its beds contain. Plumbago, one of the three forms of carbon, is also a product of the Metamorphic System.

The Laurentian Rocks are divided into Lower and Upper. The former attain a thickness of 20,000 feet, and the latter of 10,000 feet. These rocks are stratified, and they have become highly crystalline. The oldest fossil yet found appears to be a foraminifer discovered by Sir W. Logan in 1859 in the Lower Laurentian, but the Upper has hitherto afforded no fossil.

The Cambrian Group is divided into Lower and Upper. The Lower Cambrian or Longmynd group is composed of sandstones, which are found in the Longmynd hills to be some 6,000 feet thick, and the Llanberis slates, about 3,000 feet to 4,000 feet, the whole thickness of the Longmynd group being about 10,000 feet. The oldest fossils in Europe are found in this group. The Upper Cambrian consists of slates and flags, of a thickness of some 8,000 feet. The trilobite, a remarkable crustacean, characteristic of the Silurian period, first appears in this group, and the group bears evidence of a great advance in life. The Cambrian is largely developed in North Wales.

The Silurian System is also typically exhibited in North Wales. The Lower and Upper Silurian have a thickness of 20,000 feet, and contain many alternations and gradations from freestone to sandy flags, from flagstones to shales, and from shales to calcareous flags and limestones of varying thickness and purity. The fossils of the Silurian are eminently marine, and consist of numerous species and genera of zoophites, radiata, molluscs, annelids, and crustacea, the most characteristic being the trilobite. Traces of fishes are found on the uppermost verge of the system, or in beds which by some are considered as the basis of the Old Red Sandstone, but there is yet no evidence of any terrestrial fauna.

In an industrial point of view, the rocks of the Silurian are of no great importance. Roofing slates and flagstones are quarried, but are not of the best quality, and building stone and limestone for mortar and manure. Metallic veins of ore, such as mercury, copper, lead, silver and gold, traverse the system.

The Devonian or Old Red Sandstone, as the name indicates, consists of sandstones and limestones, the whole being more or less coloured by the peroxide of iron. The organic remains furnish distinct evidence of terrestrial vegetation, as well as the earliest traces of vertebrate life on our globe. The plant remains are by no means plentiful, but the fauna of the system is much more abundant. Many genera of corals, encrinites, shells, and crustaceans are found, some of the crustaceans being of gigantic proportions. The fishes seem to have thronged the waters of the period, and their remains are often found in masses in some places, and wonderful creations they appear to have been. The existence of reptiles during the Old Red Sandstone period is a disputed point. The Old Red Sandstone is from 3,000 to 8,000 feet thick. Commercially, it is not of much importance. It yields flagstones, building stones; the felspars, porphyries, and greenstones are durable, but difficult to dress into form because of their texture.

No geological era has bequeathed to us a more valuable deposit than the Carboniferous Period, which succeeds the Old Red Sandstone. Interstratified

with the rocks we find those valuable seams of coal which are the greatest wealth of a country.

The system is generally separable into four well-marked groups—viz., the Lower Coal Measures or Carboniferous Slates, the Mountain Limestone, the Millstone Grit, and the Upper or True Coal Measures.

The Carboniferous strata throughout are composed of frequent alternations of sandstones, shales, limestones, coals and ironstones.

The *Lower Coal Measure* fossils are of a distinctive character, and seem to point to a fresh-water rather than a salt-water origin. The iron which impregnated the waters of the Old Red Sandstone period and tinged with rusty red the whole of that system, now appears in the form of thin layers and bands of ironstone. The thin seams of coal point to a new exuberance of terrestrial vegetation and indicate a genial climate. The Lower Coal Measures are very scantily developed in some districts and in others attain a great thickness, so that it is almost impossible to state their thickness, although frequently given at 1,000 feet, the Mountain Limestone at from 500 to 1,400, the Millstone Grit at 600, whilst the True Coal Measures vary from 3,000 to 12,000 feet thick.

The *Mountain Limestone* is the most distinct and unmistakeable group in the whole crust of the earth. Its limestones and fossils are so marked and peculiar as to form a guiding post to the miner and geologist. By far the greater part of the workable coal seams of Scotland is included in the Mountain Limestone group. Again, the Mountain Limestone is absent from both the Shrewsbury and South Staffordshire coal-fields, the true coal measures there resting on the Cambrian and Silurian Rocks, whilst in Worcestershire, the Forest of Wyre Coal Measures rest on a bed of Old Red Sandstone. In Shropshire the Silurian rocks form the general foundation to the carboniferous formations.

Between the Mountain Limestone and the Millstone Grit are a thick series of black shales called the Yoredale rocks.

The *Millstone Grit* is composed of a series of hard and coarse sandstones and shales, usually of a grey, white, or yellow colour, but sometimes red. It is sometimes absent and never attains a greater thickness than 1,000 feet, except in Ireland, where it is said to be 1,800 feet in some parts. Occasionally it contains thin seams of coal, but is known to miners by the name of the Farewell Rock, suggesting that, on a sinking reaching this rock, farewell has been said to the coal seams of the Upper Coal Measures.

In Derbyshire the Mountain Limestone consists of an enormous mass of calcareous rocks almost destitute of sedimentary matter and entirely so of coal. Further north in Lancashire and Yorkshire workable coal seams are found at a stage earlier than the true Coal Measures—in the Millstone Grit. Still further north, in Northumberland, several beds of coal are found near the base of the Mountain Limestone formation. The coals of the Mountain Limestone of Scotland occupy a position similar to that of those in Northumberland, but in Scotland the sedimentary strata are more largely developed.

The *Upper Coal Measures* furnish us with those valuable beds of coal which contribute so much to our country's prosperity and power. The series sometimes occur immediately above the Mountain Limestone, the Millstone Grit being then wanting. One of the most notable features in its composition is the frequent recurrence of seams of coal, of bituminous shale, all speaking of an enormous profusion of vegetable growth. The organic remains of the Coal Measures are peculiarly well defined. The fishes are chiefly of large size, and of a sauroid character. In certain fields are evidences of terrestrial life in the skeletons of reptiles, fragments of land shells, and remains of insects. The great feature of the period, however, is the abundant flora, which comprise forms which are now only distantly represented in tropical swamps and jungles, and point to a tropical condition of climate.

It must be borne in mind that the coal is composed of carbon, hydrogen and oxygen, elements which enter into the composition of vegetable organisms, so that the coal seams are not the result of a deposition, like the associated sandstones and shales. The most reasonable theory as to the origin of coal seems to be that it is the remains of vegetable matter which became decomposed and mineralized on the spot where it grew, and where it is now found. The luxuriance and profusion of the vegetable growth point to conditions of climate very different from our own at the present time. This vegetation would be produced abundantly on the borders of great lakes and estuaries, and vast lagoons would be formed. In process of time these layers of vegetation would be carried down beneath the sea-level, which consequently flowed over it, depositing layers of sand, silt and mud, which we now find alternating with our coal seams as beds of sandstone and shale. The downward movement must have been irregular or intermittent, and in the long pauses the sediment would fill up the lagoons, and fresh jungles would spring up, which, when the downward movement set in, would be in turn entombed beneath the silt and mud of the sea waters. Each coal seam thus represents the vegetation of an old land surface, and the alternations of sandstone, shale, fire-clay, &c., represent the different sediments which were brought together by the combined action of the sea and estuarine waters during the slow and irregular subsidence of their beds. It will be noticed that nearly all coal-fields are basin-shaped, and that each coal seam has characteristics peculiarly its own, often prevailing over very wide areas. Besides the distinctive features in the formation of coal seams, the coal obtained from one differs from that yielded by another, and frequently one coal seam gives different qualities of coal.

The differences arise chiefly from the difference of chemical composition, as the hydrogen, oxygen and carbon are present in the coal in varying states of combination.

Different samples of coal give out amounts of heat during combustion which are not always anticipated from their chemical composition, or the heat which would be expected from analysis.

For this reason the different coals used in boiler tests should be experimented on, to ascertain the actual heat of combustion, as well as that estimated from analysis, otherwise the results of the tests made may be quite misleading.

Commercially the Carboniferous is the most important and valuable system to man. It yields building stone of the best quality, limestones for many purposes, marbles, fire-clay, ironstone, ochre, alum, copperas, and coal of various qualities. The Mountain Limestone yields ores of lead, zinc, antimony, and sometimes silver and gold.

Succeeding the Coal Measures we have the PERMIAN. It would seem that the iron which occurred in such quantities in the Carboniferous period is found in the Permian above and in the Old Red Sandstone below in the state of an oxide tinting the sandstones red. The Limestones of the Permian are remarkable for the fact that they in some places contain 44 per cent. of carbonate of magnesia mixed with the carbonate of lime. Its fauna is like that of the late palæozoic era, the fish still retaining the heterocercal tail, but after this we find the homocercal tail gains the ascendancy, until in our own time only a few heterocercs exist. The Permian has not many striking features: a few veins of lead and zinc traverse the magnesian limestone, but the deposits are not rich. It yields also building stone, gypsum from some of the marls, and in Germany the *Kupfer-schiefer* has been long mined as an ore of copper. The Permian is about 600 feet thick.

The TRIAS or NEW RED SANDSTONE, the latter name being given because reddish hues prevail throughout its sandstones and shales in the British Isles,

as a group is very imperfectly developed in England, but in Germany the formation is well exhibited. In it the clays, the limestones, and the sandstones are so distinctly arranged as to give rise to its name of Trias. The limestone deposit is wanting in England, and as the best fossils are to be found in these limestone rocks we have not the local facilities for an extensive knowledge of the flora and fauna of the period. The plants of the Triassic have a strong resemblance to the flora of the Lias and Oolite above, consisting of ferns, cycads, and conifers. The industrial products yielded by the system are sandstones of varying quality, calcareous flagstones, limestone, gypsum, and rock-salt. The Trias is about 1,400 feet thick in England.

The Lias, which follows the Trias, is composed of dark argillaceous limestones, bluish clays, and bituminous and pyritous shales. The fauna of the period is diversified and interesting. Upwards of 120 species of ammonites have been discovered. The most interesting feature in the life of the age is the appearance of reptiles of extraordinary size and structure, such as the Ichthyosaurus and Plesiosaurus.

The ironstone of Cleveland, in Yorkshire, which lies in thick beds, is in the Lias and is now extensively worked. Ironstones in other parts have also been found in the Lias.

The Lias is about 800 feet thick and yields a limestone largely quarried for mortar and hydraulic cement.

The Oolite.—Above the Lias in the South and West of England is the Oolite. It consists of alternations of oolitic limestones, calcareous grits, shelly conglomerates, yellowish sands, and thick bedded, bluish grey clays more or less calcareous.

The flora of the era was extensive, as may be gathered from the fact that at Brora, in Sutherlandshire, there is the thickest stratum of coal found in any English Secondary rock. It has been worked for a long period, the seam being $3\frac{1}{2}$ feet thick. Near Richmond, Virginia, is a coal-field of considerable extent belonging to the epoch. The Oolite yields sandstones like those of Bath and Portland, excellent for building purposes. It also yields Fuller's earth, jet, a compact variety of coal, and lignite or wood coal is also found, but it is not of much economic value. The Oolite is about 1,800 feet thick.

The Cretaceous System.—The lowest member of the Cretaceous is the Wealden; this deposit is of fresh-water origin, and there have been no ammonites, nor corals, nor a shell which tells of the presence of the sea in the Wealden group. But the bones of terrestrial animals and the fossils of land plants, all declare that the Wealden owes its existence to some great river which brought down mud from the continent it drained, depositing a delta. The Upper Cretaceous is composed of well-defined marine sands, dark marl clays, and thick beds of chalk. The organic remains found are sponges, corals, star fishes, molluscs, crustacea, fishes and reptiles. The fossil plants are comparatively rare. Industrially, the chief products of the system in Great Britain are chalk and flint. Several of the workable coal seams of Vancouver Island, and British North America, belong to the Cretaceous epoch. The Cretaceous is over 2,000 feet thick.

The Tertiary, following the Cretaceous, offers phenomena in its beds and fossils not unfamiliar to modern observation. From the similarity of the forms of life of the Tertiary epoch to those animals which are now found on the earth, the period, looking at it from this point of view, has been called *Cainozoic*. The Tertiary is not typically developed in England. The lower groups consist of

clays, sands, and gravels, with interstratified limestone, calcareous grits, marls, and occasional layers of lignite. The industrial products are building stone and marbles of various quality; pipe and potters' clay, gypsum, or the well-known "Plaster of Paris," Lignite or "brown coal," and amber. The Pleistocene is the Upper group of the Tertiary, and it embraces under one head the clays, sands, gravels, and boulders generally known as the Glacial period, or "drift formation." It is almost unfossiliferous. In some parts of Britain the drift consists of fragments of all the older rocks, from the granite to the chalk, inclusive.

It would appear that this "drift" was the result of an Arctic or frozen climate setting in after the deposition of the lower group of the Tertiary, with glaciers to wear and furrow the surface of the land, and with icebergs and ice-floes dropping off the shore to transport the eroded material into deeper water. The Tertiary is about 2,800 feet thick.

A remarkable instance of rock believed to have been deposited in glacial times, is that at the Stevens Mine, in Mount M'Clellan, California, its altitude being 2,500 feet. At a depth of from 60 to 200 feet, the vein, consisting of silicia calcite and ore, and also the surrounding wall rocks are a solid frozen mass. Many other mines in the same vicinity have similar belts of frozen ground, and as they are at considerable depths from the surface, where there are no openings for air currents, the theory is that the frozen mine is due to imbedded icebergs of the glacial period. There has been no diminution in the frost in descending, and the frozen material is so hard as to render the miner's pick and drill of no use in excavating it.

The Post-Tertiary embraces all the accumulation and deposits formed since the Glacial period. At its close the present distribution of sea and land seems to have been established. Page says, in his work on Geology, to which reference has been made in preparing this chapter, that the earth also appears to have then had its present flora and fauna with the exception of some local removals of certain plants and animals and the general extinction of a few species. Theoretically the accumulations of the present era are not only of high interest in themselves, but of prime importance in furnishing a key to the complicated phenomena of former epochs. Practically they present many important features to the farmer, engineer, and navigator, and furnish us industrially with such products as brick, clay, sand, marl, peat, pumice, sulphur, brown coal, and amber.

CHAPTER II.

SEARCH FOR COAL.

In Untried Districts by the Application of Geological Knowledge—Search in both an Unknown and Proved Coal-field by Boring—The Operation of Hand-boring by the Use of Rigid Rods—Boring with the Diamond Drill—Application of the Result obtained by a Series of Bores—Search for Coal in South Staffordshire—Search for Coal in Kent.

The search for coal in an altogether unknown district is putting the geologist's knowledge to a practical test. He carefully examines the district, making use of roadsides, quarries, cliffs, protruding rocks, the beds of streams, railway cuttings (if any) and ploughed fields. He may by these means be able to ascertain whether the rocks are carboniferous, and if so he must pursue his investigations further. An actual outcrop of a coal seam may be discovered, or the dark appearance of the soil over a freshly ploughed field may indicate the proximity of one, in which case he would remove the soil at places most likely to prove the existence or otherwise of coal, and having found it, he would probably drive a heading into it to prove its dip for some little distance, the direction and amount of which would be noted. But should he have proved the rocks to be unquestionably carboniferous (and the fossils should be an infallible guide to him) his failure by a personal examination to find coal will by no means be conclusive, and he will have to resort to boring. Sometimes, too, the coal measures are covered by the secondary or tertiary rocks, beneath a comparatively thin covering of which the coal measures may be found. Even in a district where coal has been proved and worked, it is often necessary to bore, as before deciding on the site for a shaft it is of importance to know the direction and amount of dip, the nature of the rocks to be sunk through, and the quality and number of the seams to be won. The outcrop of a seam, it must be remembered, affords but little indication of the quality of the coal, as it is much deteriorated from being exposed to atmospheric influences. A personal survey having met with encouragement, boring should be resorted to so that the depth and thickness of the seam or seams, and their inclination, may be ascertained to guide the sinking of shafts to win the coal.

The operation of boring may be classified under two distinct heads. The first proceeds by means of a suspended tool, to which is given a percussive motion by either hand or steam-power, and also a rotary motion either by the apparatus itself or by the attendant, the latter motion taking place between each fall of the tool. The second consists in giving motion to a rotating tool which is hollow in the form of a tube, as in a drill used by a Diamond Boring Co.

The ordinary process of hand-boring consists first in erecting the *headgear*, Fig. 4, over the bore-hole for the purpose of supporting the tackle by which the bore-rods are drawn out of or lowered into the hole, when it is necessary to clean out the hole or change the cutting chisel. The headgear may be made of three good, sound Norway spars 8 or 10 inches in diameter, 40 feet high, and formed as a triangle; or four legs may be used with cross pieces; a pair of blocks are hung from the top, or they may be further multiplied according to the depth of the hole. A rope is passed through the blocks, one end of which is attached to a winch and the other hangs loose over the end of the bore-hole. The windlass should be 12 inches in diameter and be fitted with a pawl and brake, so as to

regulate the speed with which the rods are lowered. The following are the tools used as described by Greenwell in his *Mine Engineering*:—

The Ordinary Bore-Rods, Fig. 5, 1 inch square, made of best wrought iron 6 or 9 feet long with a male screw at one end and a female screw at the other.

Lengtheners are from 4 to 30 inches long, and of the same section as ordinary rods.

Chisels, see Fig. 6, are 18 inches long and from 2 to $2\frac{1}{2}$ inches in breadth on the face, which is of the best steel; they weigh about $4\frac{1}{2}$ lbs.

Fig. 5.—Ordinary Bore-Rod.

Fig. 6.—Chisel.

Fig. 7 —Wimble.

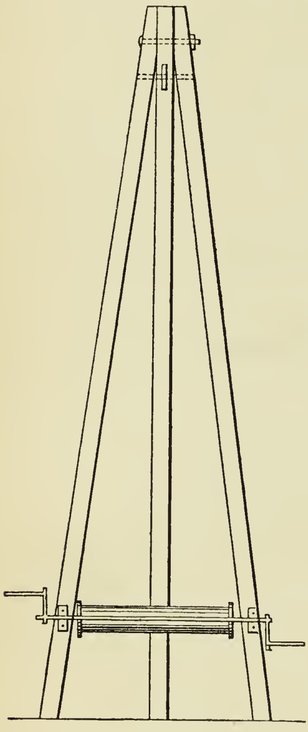


Fig. 4.—Head Gear and Windlass for Boring.

Fig. 8.—Bêche.

Fig. 9.—Rounder.

The Wimble, Fig. 7, is 3 feet long, the lower 2 feet being cylindrical, the bottom being partly covered for the purpose of retaining the core in the instrument. It is made of wrought iron of a size suitable "to follow" the chisel.

There is an opening a little up one side of it to admit of the loosened material entering it. The wimble is also used for boring through clay.

The Sludger is also 3 feet long and somewhat resembles the wimble; the lower cylindrical part has no opening in it, but the bottom has a clack for the purpose of retaining borings of a soft nature.

The Bêche, Fig. 8, is used for the purpose of extracting broken pieces of rod in case of fracture. It is about 25 inches long and hollow for about 16 inches up. The diameter of the cavity at the bottom is $1\frac{3}{4}$ inches tapering up to $\frac{5}{8}$ inch.

In case of the rods breaking, the part above the fracture is withdrawn, the bêche being screwed on to take the place of the broken rod. It is then lowered sharply on to the broken rods in the hole, the force causing them to enter the tapering cavity of the bêche, which grips them whilst they are drawn up.

Rounders, Fig. 9, have the appearance of the bêche, but are solid and well steeled at the bottom. They are used for breaking off any irregularity in the holes.

The Bracehead, Fig. 10, is a piece of oak or ash 3 feet long and 3 inches in diameter in the centre tapering slightly towards either end, and this is passed through an eye formed in a piece of iron screwed on to the top rod. A man stands at each side to lift the rods and turn them partly round in the hole. For greater depths than 10 fathoms a double bracehead is used. It consists of two similar pieces of wood passed through two eyes in the iron at right angles to each other. Four men stand one at each arm of the double bracehead, to lift and turn the rods, and thus a depth of 20 fathoms is attained.

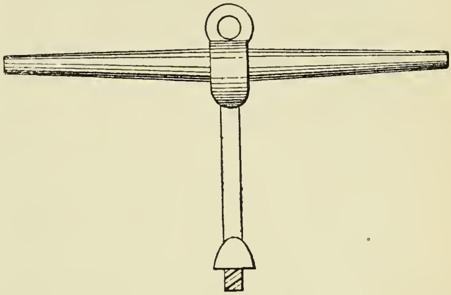


Fig. 10.—Bracehead.

A Brake, Fig. 11, is used below a depth of 20 fathoms. This is simply a lever of Memel fir 10 or 12 feet long, the fulcrum being 18 inches or 2 feet from one

Fig. 11.—Brake or Lever for Boring.

end. At its extremity is placed an iron crook, a rope being attached to it and to the bracehead. Two or more men at the other extremity press down the brake

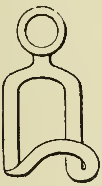


Fig. 12.—Runner.

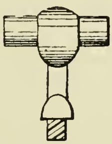


Fig. 13.—Topit.

Fig. 14.—Key.

and so raise the rods, another man then turns the bracehead partly round, and the men at the brake let it go suddenly, causing the chisel to cut into the ground. When it is desired to take the rods out, the bracehead is unscrewed and a *runner*, Fig. 12, is attached to the rope which fits on to the *topit*, Fig. 13, which is then screwed on to take the place of the bracehead. The windlass is used for drawing up the rods as far as the shear-legs will allow, when a *Key*, Fig. 14, is passed under the bottom joint above the bore-hole, and this key holds them in position whilst another key is used for unscrewing them.

Another topit is screwed on the remaining portion of the rods, and by means of the runner another portion lifted by the windlass. The process is continued till all the rods are drawn out.

Fig. 15 shows a group of improved boring tools, as manufactured by Messrs. Thornewill & Warham, of Burton-on-Trent, and supplied by them singly or in sets.

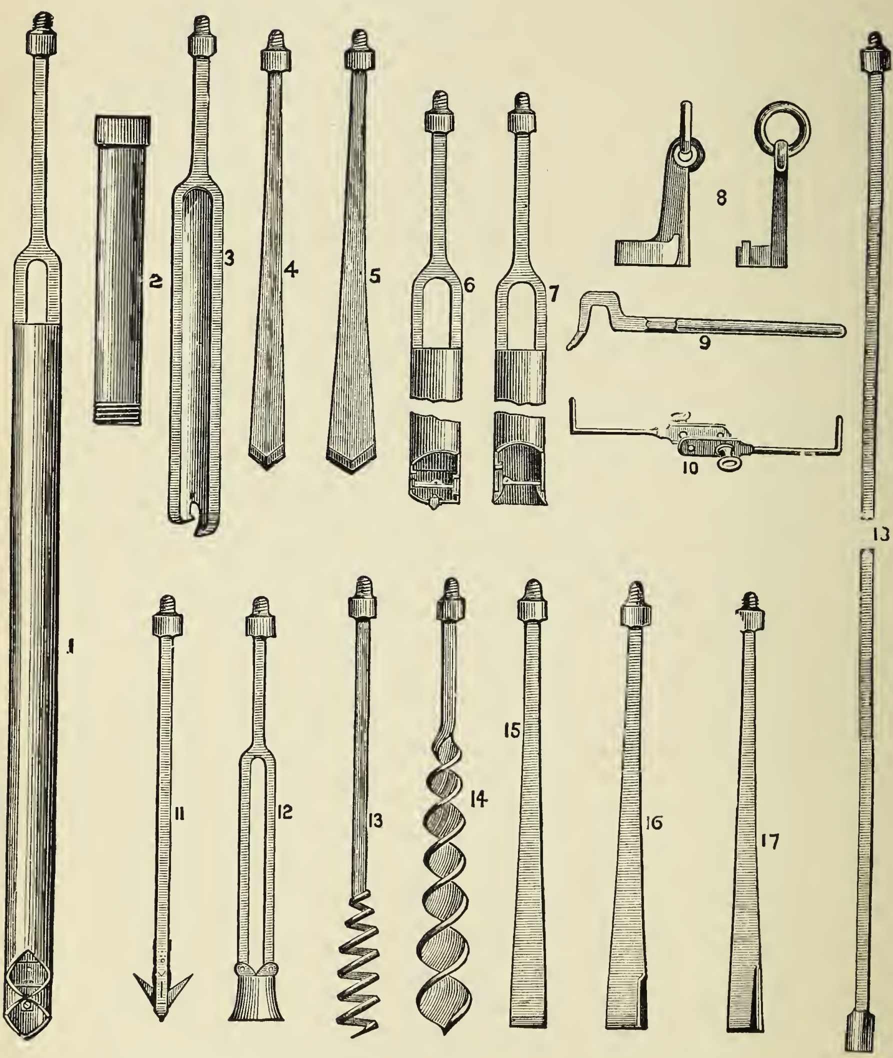


Fig. 15.—Messrs. Thornewill and Warham's Improved Boring Tools.

List of Boring Tools in Fig. 15.

1. Shoe-nose shell with valve for bringing up loose stuff.
2. Wrought-iron screwed well bore pipes.
3. Auger for clay and stiff soil.
4 and 5. V-nose chisels for hard ground.
6. Shell-auger with valve for loose and wet soil.
7. Bell-shell with valve for loose gravel.
8. Lifting dog for raising rods.
9. Pair of rod-wrenches for screwing and unscrewing rods.
10. Levers for turning rods.
11. Spring dart for drawing pipes in bore-holes.
12. Bell-box for bringing up broken bits.
13. Spiral worm for extracting broken rods.
14 Worm auger for loosening stuff in bore-holes.
15. Square-nose chisel.
16. S-nose chisel for hard strata.
17. T-nose chisel for hard strata.
18. Rods with screw joints in 5 and 10-foot lengths.

The depth of a bore-hole is measured by the number of rods, and the kinds of strata judged by the borings brought up by the tools used. Changes in the stratification are noted by the charge-man, who is guided by the sound and sensation through the hands when the rods fall, and he marks each change on the rods.

As the depth of a hole bored in this way increases the rate of progress decreases, and when a great depth has been reached a considerable amount of time is occupied by the necessary changes in the tools, and very little in actual boring. In cutting hard rocks far beneath the surface this system is extremely slow and expensive. A steam engine may be used, so as to give more power in lifting the weight of rods, which becomes excessive as the bore-hole reaches a great depth, but even then the process does not admit of rapid boring. The vertical engine usually gives motion by means of belting to a shaft carrying a cam roller, and this lifts a wooden beam or lever near that end from which the boring rods are suspended. At every two or three revolutions of the small engine the cam roller makes one, thus raising the beam and allowing it to fall. The other end of the beam rests in a trestle, which acts as the fulcrum, and allows of change by sliding the trestle nearer the rod-end of the lever. Between it and the cam roller is placed a strong, upright column to receive the lever on its descent, and this is protected on the top by a cushion of india-rubber to break the shock.

In boring by the diamond drill a wrought-iron H-shaped frame is used to carry the machinery necessary for boring, pumping, and raising the rods. A portable engine is used to do all the work, and the system requires only the services of two or three attendants. The power is transmitted from the engine by means of belting and an arrangement of gearing. A set of shear-legs is erected which carries a pulley immediately over the bore-hole, and one end of a chain passes over this pulley, the other being attached to a power-crab, which may be set in motion by the steam engine when desired. By this means the rods are raised and lowered. The machine carrying the cog-wheels and shafting is moved when it becomes necessary to draw the rods. To render this easy a short length of rails is laid down to receive the machine, and facilitate changes in its position.

The boring rods are carried, and receive their rotary motion by means of a vertical hollow rod. Attached to the upright side-frames of the machine are slides, and in these work a crosshead having a rise or fall the length of the slides. It supports and guides the vertical rods, so as to ensure their being perpendicular.

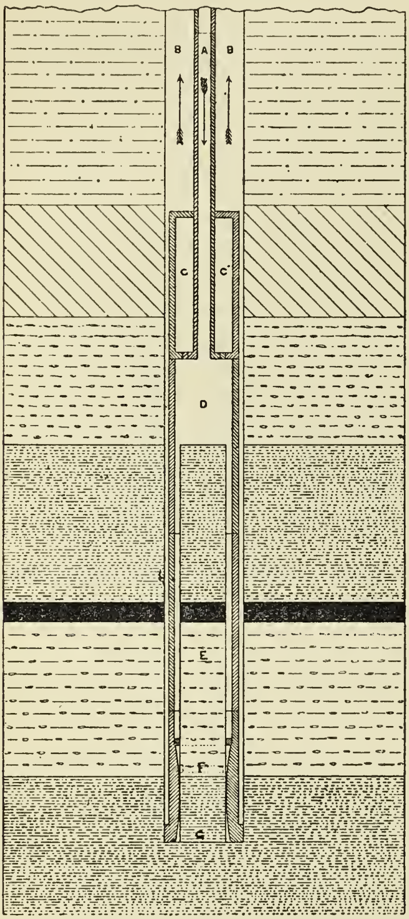
This cross-head also conveys the necessary pressure to the crown whilst rotating, balance weights being attached to it by chains and pulleys.

The pressure is controlled and regulated by means of the weights. The upper part of the rod is slotted, thus allowing of its upward movement through the cog transmitting the power, and on the top is placed a water union, joined up to a force-pump by means of flexible hose and iron pipes. The pump is set in motion by means of a belt and suitable gearing.

The boring tool consists of different parts, and is shown in Fig. 16, G being the crown, F the core-trap, E and D core-tubes, and C a sediment tube.

The crown, G, is a steel ring, having grooves cut in it as shown in the drawing, which enable the water to pass freely under it as the boring proceeds. There are 9 diamonds placed in the crown, 3 being inside, 3 outside on the base, and 3 on the circumference. For large holes more diamonds are fixed in the crown. The diamonds are placed in holes prepared to receive them according to their shape, and the metal is drawn round on every side of each diamond by means of a punch, until only a very small portion of the stone projects beyond the surface of the steel ring.

The crown, G, screws into the core-trap, F, which is a short length of steel tube of special construction, the inside being slightly convex. In it is fitted an expanding ring for securely holding the core whilst the rods are being drawn. There is nothing special in the construction of the core-tubes, E and D; they are made of steel, and threaded at the ends for attachment. One or more lengths of core-tubes may be used, but if only one be attached a core of great length cannot be extracted; it also renders necessary a more frequent change of the rods.



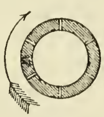


Fig. 16.—Method of Boring with the Diamond Drill.

In hard rock 20 feet is the length of core-tube adopted, and for this length the shear-legs must be 40 feet high.

The top of the core-tube is solid, but is provided with a threaded opening in the centre, into which are screwed the boring rods, A. Above the core-tube is the sediment tube, C, screwed on to it. Its object is to collect the sediment washed from under the crown as the boring proceeds. As shown in the drawing the crown is slightly larger than the other portions of the boring tool, so as to reduce friction.

The manner of procedure is as follows:—

The boring tool, with one length of rod attached, is lowered into the bore-hole by means of the chain over the shear-legs pulley, and is then suspended by clamps placed over the bore-hole until one or more lengths of rods (which consist of ordinary tubes threaded at the ends) are raised by means of the chain, and attached by screwing to the rods held by the clamps. All is then lowered together, and again suspended by clamps. This process is repeated again and again until the crown reaches the bottom of the bore-hole. The machine is then moved forward on the rails into its working position, the cross-head lowered, and the hollow shaft screwed on to the boring rods.

The rods are then given a rapid rotary motion (from 200 to 300 revolutions per minute), and the motion of the rods being transmitted to the crown an annular channel is cut by the diamonds, and as the rods descend the core formed inside the channel enters the core-trap, and afterwards the core-tubes. As the

rods are revolved the pump is set in motion, and water is forced down the hollow rods, A, as shown by the arrow, at a pressure which must be sufficient to cool the crown, and keep it clean by sweeping away the eroded material. After passing under the crown the water returns to the surface by the annular space formed between the walls of the bore-hole and the boring rods, as shown by the arrows.

Unless the ground is soft and friable the core formed is solid, and will not break till the act of withdrawing the rods takes place, when it parts at the base and is retained within the core-tube by the expanding ring. Upon reaching the surface these cores are all accurately numbered and safely housed by the attendant in charge, who also enters all notes as to stratifications between the numbers of cores not extracted, and is responsible to his employer for the preservation of an accurate account of the strata.

In boring through surface clays or other soft material, the ordinary method of boring compares favourably with the diamond drill, but in hard strata and for depths exceeding 100 yards, the diamond drill works to great advantage, being more expeditious and not more costly.

The bore-holes may be wholly or partly lined with tubes to prevent the lateral pressure choking the hole, and also to prevent water entering from the strata at the side, which would otherwise represent a certain amount of pressure to be overcome in maintaining the water-flow pressure down the boring rods. The lining tubes in some instances are quite as necessary in some sections of dry borings, in order to prevent the feed-water escaping through porous strata frequently found near the surface and always adding to the power required to maintain a given pressure of water. Occasionally a bore-hole is commenced by the ordinary method, and on reaching a certain point where harder strata are found, it gives way to the diamond drill. Again, a bore-hole is sometimes undertaken by the diamond drill from the bottom of an existing shaft to prove the lower strata there. In some instances borings have been put down by the diamond drill from the bottom of heavily watered sinking pits to the coal workings below, after which the sinkers were enabled to proceed in a dry shaft to complete the sinking. The diamond drill cuts the hardest rock at rates varying from 2 inches to 8 inches per minute.

In bore-holes of small size, unless the seams of coal passed through are extremely hard, the action of the drill grinds them and the specimens appear in the core-box in a pounded condition. If the bore-hole is of somewhat larger size, this will not be so noticeable, and if the specimen of the coal seam is protected by hard rock over it in the core-box as shown in the drawing, a very perfect specimen of the seam may reach the surface. Where, however, the coal is of a soft nature and it forms the top portion of the core entering the core-box, the weight of water in its descent will wash a considerable portion of the coal away, and this may lead to an erroneous section of it. A valve has been placed on top of the core-tube with a view to take the weight of water off the whole core, and possibly some of the Boring Companies adopt this practice now.

The diamond used is in a different state from the gem, and is technically called a carbonate, but the substance is really carbon in an imperfect state of crystallisation, and this rough diamond while as hard as the ordinary diamond, does not so easily break. It is black in colour, and may easily be mistaken for coal; it is supplied from the mines of Brazil in the district of Bahia; and no diamonds of the same class or quality have been found in any other diamond fields. Experiments have been tried with other substances, but none compare with the carbonate in fitness to cut hard strata. A piece of carbonate the size of a large pea, will cut a hole in sandstone, half a mile deep or more, without sensible abrasion to its surface, and although in harder rocks than sandstone the abrasion is more, it is still very slight. The loss on the crown from the act of

drilling half a mile is very slight, but the diamonds get broken from other causes. If a jar breaks one, it causes more jarring and leads to the breakage of others, and as the diamonds are costly, the loss to the Boring Company becomes serious.

A great advantage of the diamond-drill boring is that the hole is kept true and vertical, and this cannot be assured in other systems. Then the cores frequently contain whole and uninjured fossils characteristic of the strata, which but for this evidence would remain uncertain of classification. Thus the sub-committee of geologists connected with the Sub-Wealden bore-hole near Hastings, state that the determination at which they arrived with reference to the position of the strata was "due to the manner in which large cores were brought to the surface by the Diamond Rock-Boring Machine, so that a number of fossils were obtained entire, the species of which could be accurately determined."

The percentage of cores obtained by the diamond drill seems to vary from about 60 to 90 in bore-holes of small size. The boring rods are subject to accident, occasioning delays, such as breakages and jams, but they are not more difficult to deal with than are the breakages inseparable from other modes of boring. When a trial of the diamond was first made to ascertain its suitability for the purpose of boring, it was given a percussive motion, but experience soon showed it to be better adapted for abrasion.

On the introduction of the system the holes drilled were under 2 inches in diameter, and the cores produced were about $\frac{3}{4}$ of an inch in diameter. Consequently difficulty arose in securing cores in soft strata, although the result in hard rocks was quite satisfactory. On this account and also to give room for lining tubes, the bore-holes have been gradually increased in size. Where they have been of large size, 100 per cent. of cores of the strata have been obtained even with the softest of rocks. For instance at Caerphilly, in South Wales, in a hole put down to a depth of 1,007$\frac{1}{2}$ feet in 1874, the cores yielded showed a complete section of the strata passed through, and the samples of coal were satisfactory.

Bore-holes of 26 inches in diameter yielding cores 23$\frac{1}{2}$ inches in diameter have been put down by the diamond drill.

The deepest bore-hole known is that made at Schladebach, Leipzic, to a depth of 5,736 feet. It was commenced 11 inches in diameter in the Trias, and after passing through the Permian entered the Old Red Sandstone, the size of the hole having been reduced to 1·22 inch at the bottom.

A bore-hole at Sperenberg, Berlin, was made by means of rigid rods to a depth of 4,170 feet, and took 4$\frac{3}{4}$ years to accomplish. A boring for salt near Lubtheon, in Mecklenburg, was carried out by a diamond drill to nearly 4,000 feet, and was completed within 6 months. The boring was not only wonderfully successful in the speed with which it was accomplished, but was further distinguished by the hole yielding 100 per cent. of cores, one specimen of rock-salt being over 20 feet long.

No virgin property of a size to require any borings on it, should have less than three, and it may be wise to put down more; but in a neighbourhood free from faults and dykes, and proved by winnings all round, none will be necessary. It is natural to let the first be nearest the rise. It must be remembered that the depths as proved by boring through inclined strata do not give the true thicknesses of such, as the bore-hole is perpendicular and the line of stratification does not often form a right angle to it. The true thickness of a stratum is found by multiplying the thickness as proved in the boring by the cosine of angle of dip. Thus, if a stratum was proved to be 1 fathom thick in the boring where the dip was at an angle of 30°, the true thickness would be ·866025 of a fathom or 5·19615

feet. Tables of incline measure may be obtained showing the comparative lengths of the hypothenuse, horizontal, and vertical legs of a right-angled triangle for every degree of the quadrant.

Supposing three bore-holes to be put down on a property at equal distances apart, say 500 yards. No. 1 being nearest the rise and proving the coal at a depth of 15 fathoms, No. 2 fully to the dip of No. 1, as well as can be ascertained, proving the same seam at a depth of 30 fathoms, and No. 3 still fully to the dip of No. 2 as nearly as may be judged, proving the same seam at a depth of 50 fathoms, all the bore-holes being at the same surface level. It would appear that the dip of the strata from No. 1 to No. 2 bore-hole was 500 ÷ 60 yards — 30 yards $= \frac{500}{30} = 16 \cdot \dot{6}$, that is, 1 in $16 \cdot \dot{6}$, and from No. 2 to No. 3, 500 ÷ 100 — 60 $= \frac{500}{40} = 12 \cdot 5$, that is, 1 in 12·5, supposing there were no faults or dislocations in the strata to upset the calculation.

Suppose now 4 bore-holes are put down on a property, and there are no other means of forming any idea of the dip. No. 1 proves the coal at a depth of 85 fathoms, No. 2 is due South of No. 1, by the magnetic needle, and proves the coal at 80 fathoms, being 500 yards from No. 1. No. 3 lies S. 50 E. of No. 1, and is 300 yards distant, proving the coal at a depth of 110 fathoms. No. 4 is S. 40 W. of No. 1, 250 yards distant from No. 1, and proves the coal at $64\frac{1}{4}$ fathoms, all the bore-holes being at the same surface level. The direction of full dip and its extent may be determined as follow.

By plotting as shown at Fig. 17, or by trigonometry, it will be found that the distance between No. 2 and No. 3 would be 383·62 yards. The difference in level between the seam at No. 2 and No. 3 bore-holes is 220 yards — 160 = 60 yards and $\frac{383 \cdot 62}{60} = 6 \cdot 39$, that is the seam dips from No. 2 towards No. 3 at the rate of 1 in 6·39. Now, to find the level course of the seam, follow along the course from No. 2 towards No. 3 until a point is reached 5 fathoms or 10 yards below the seam at No. 2 bore-hole, because the difference in the depth between No. 1 and No. 2 is 85 — 80 = 5 fathoms. To gain 10 yards of fall along a course dipping 1 in 6·39 follow it for a distance of 6·39 × 10 = 63·9 yards. Therefore a line drawn from No. 1 borehole to a point in the line connecting No. 2 and No. 3, and 63·9 yards distant from No. 2, gives the level course of the seam, and by means of plotting or from the computed value of the angles, it may be seen that the bearing from Nos. 2 to 3 bore-holes is N. 36° 48′ 9″ E., and that of the level course of the seam S. 4° 52′ 29″ E. from No. 1. The full dip would be at right angles to this or N. 85° 7′ 31″ E. To get the amount of dip, draw a line connecting No. 3 bore-hole with the level course of the seam and at right angles to it. Such a line would measure 212·6 yards, and since the difference of level in the seam between the two ends of it is 110 fathoms — 85 = 25 fathoms, or 50 yards, we have $\frac{212 \cdot 6}{50} = 4 \cdot 25$, so that the full dip would be 1 in 4·25 in a direction N. 85° 7′ 31″ E.

In the same way it can be shown that a line drawn from No. 4 bore-hole to join the line representing the level course of the seam and at right angles to it would measure 176·4, and taking the dip at 1 in 4·25 as proved on the other side of the level course $\frac{176 \cdot 4}{4 \cdot 25} = 41 \cdot 5$ yards or 20·75 fathoms, and 85 — 20·75 = 64·25 fathoms as the depth of No. 4 bore-hole to prove the seam, which is the depth given, a reasonable conclusion from which would be that the coal on the property was fairly free from faults. It is only right to say that these calculations are often upset by faults running between the position of the bore-holes, and when

these are suspected to be on the property, more bore-holes should be put down before the sinking is decided on.

In coalfields having carboniferous rocks exposed on the surface the outline of the basin may be traced by following the course of outcrop of the upper edge of millstone grit or other strata underlying the carboniferous, if conformable to them. Any estate being within the coal measure or productive area as shown on

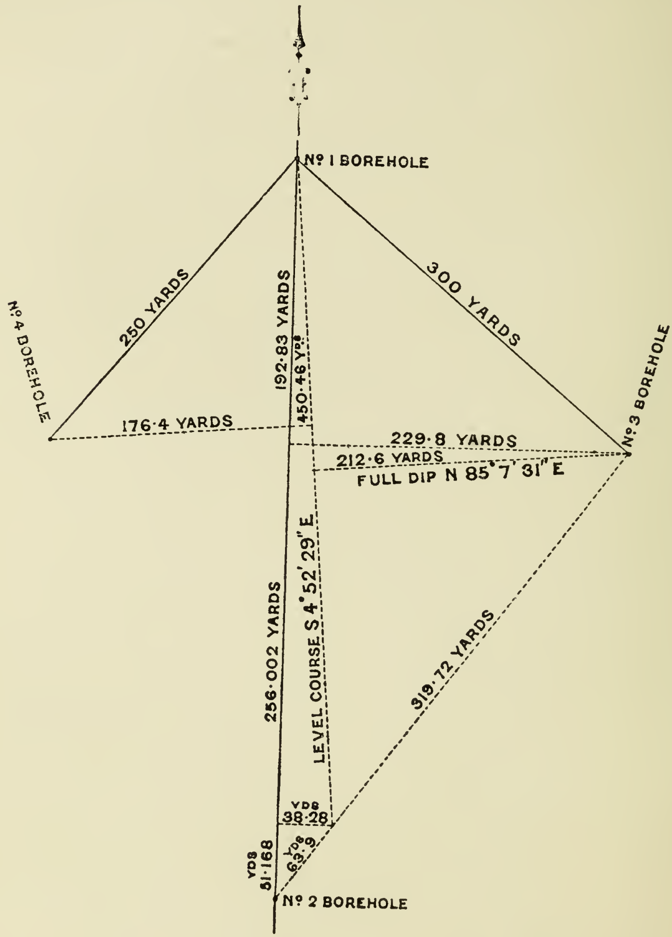


Fig. 17.—Plan showing Position of Bore-holes. Scale 6 chains to 1 inch.

a geological map would usually be expected to comprise coal seams. If situated to the rise of the lowest seam's outcrop, no coal would be available, although the rocks might belong to the lower members of the carboniferous period.

Where a coalfield is known to exist over a certain extent of country by its coal-bearing portion of the carboniferous rocks outcropping in some places and disappearing in others under Permian or newer rocks, which lie unconformably on them, there is much room for speculation as to the extent of the coalfield. Under such circumstances the search for coal of course becomes far more intricate.

As an instance of the difficulties of such a search may be cited that of the South Staffordshire Coalfield under the "red rocks."* A fault which exists in the neighbourhood of West Bromwich appeared to cut off the coal measures which are exposed to the westward. To the east of this fault the coal measures are covered by "red rocks." About 1839 the Earl of Dartmouth sank the Heath Pits ¾ of a mile or thereabouts to the east of the boundary fault, and these pits passed through Lower Permian rocks overlaying the coal measures and proved thin seams of coal, thus showing that a further productive area existed of unknown length, but ¾ of a mile in width. As the Heath Pits did not find the Staffordshire thick coal, a "heading" was driven eastward, and a boring upwards from the end of the heading proved "red rock," while another downwards from the same point struck a hard rock, afterwards believed to be Silurian. After these failures to find the thick coal, one of the thin seams was followed to the west, towards the old or previously known portion of the coal-field, and this led into the thick coal.

Sir Roderick Murchison was of opinion that the shaft had been sunk upon a line of dislocation, the continuation of the upcast of Silurian rocks of Walsall and Thame Bridge.

Professor Jukes thought there was a sudden rise of Silurian rocks through the coal measures, forming a bank, and that this bank had been favourable to the formation of sandstone and the accumulation of clay, but unfavourable to the formation of coal. Silurian shale having been found in a pit at Langley Mill, Oldbury, Professor Jukes assumed the bank to be continuous for that distance —about three miles.

While opinions differed as to what lay to the east of this bank, none were favourable to the existence of workable coal seams.

Sinkings as indicated below in the newly-found tract of productive coal measures were stated to have proved various thicknesses of red rock (Permian) resting on various thicknesses of coal measures believed to have been denuded.

	Permian over coal measures.	Coal measures over thick coal.
Lewisham Pits	315 feet	520 feet.
Lyng Colliery	550 „	350 „
Heath Pits	806 „	40 „
Bullock's Farm Pits	700 „	330 „
Unitt's Boring at the "Ruck of Stones"	664 „	Abandoned.

It was thought that these sinkings indicated a thickening of Permian beds to the eastward, while the coal measures below would unconformably be still further denuded. Professor Jukes considered it probable that a little further to the east of the Heath Pits, the coal measures would be entirely wanting, and the Permian rest directly on the shale of the Silurian formation.

The boring at the "Ruck of Stones" lies more than a mile east of Bullock's Farm Pits; and the fact that the strata between them have a dip eastward of about 10 degrees, shows that the 700 feet of Permian at Bullock's Farm are wholly below the 664 feet proved at the "Ruck of Stones." From this Professor Jukes estimated that in the neighbourhood of West Bromwich there must be at least a total thickness of 1,500 feet of Permian rocks.

On the assumption that the coal measures had not been subject to denudation and that the rocks to the eastward of the Silurian bank retained a normal thickness, it was argued that in any sinking for thick coal 1,500 feet of Permian and 1,000 feet of upper coal measures might be expected before reaching it.

* See Colliery Guardian, May 14th, 1875.

For many years these opinions of geological authorities had the effect of preventing trials on the doubtful ground, but at last the Sandwell Park Colliery Company, under the direction of Mr. Henry Johnson, made the venture, and as a reward for their enterprise struck the thick coal at 418 yards from the surface about the beginning of 1875.

The red rocks at Bullock's Farm and other West Bromwich sinkings were proved by the Sandwell Park sinkings to be coal measures instead of Permian as previously supposed. The Sandwell Pit is a mile to the eastward of Bullock's Farm. As fixing the position in the pit where the coal measures were struck, fossil plants found at a depth of 110 yards in red measures were stated by authorities on the subject, to be Permian. At a depth of 200 yards a thin seam of coal 7 inches thick was proved. Above the coal was a black shale containing fossil plants, some of which were identical with those found at 110 yards, whilst beneath the coal was a bed of fire-clay containing *Stigmaria.* At 230 yards a second coal seam 6 inches thick was struck, and a third of the same thickness at a depth of 244 yards, while at 418 yards the thick coal, the object of this patient and enterprising search, was attained. The shaft therefore entered the coal measures at a depth of 110 yards or less, showing that there is a greater thickness of coal measures over the thick coal at Sandwell Park Colliery than was proved by the pits previously sunk through the Permian strata.

As another instance of a successful search for coal we may mention that near Dover, in Kent. This discovery is full of interest to the geologist, and as it is within a workable depth it may create a very important industry in the South of England.

Previously, no true coal has been found in England to the south of a line joining Bath and Stamford and continued to Great Yarmouth, though lignite coals were known to exist in the Wealden strata of Kent, Surrey, and Sussex. An examination of the formations of strata (which are much newer than the carboniferous) prevailing over most of the area indicated would of itself not appear hopeful, yet geologists have reasoned for many years that there was a possibility of finding coal under these newer formations and within a reasonable distance of the surface.

About the year 1855 Mr. Godwin-Austen started this theory, but Sir R. Murchison, another eminent geologist, disputed it. In 1871 Professor Joseph Prestwich, who had accepted the theory started by Mr. Godwin-Austen, presented a very careful and elaborate report to Parliament on the subject.

The main feature which gave rise to the theory, is the fact that a great axis of elevation extends from the South of Ireland to Westphalia, a distance of 850 miles. Its existence can be traced at one extremity from Ireland to Frome in Somersetshire. Along the strike the lateral pressure elevated the fractured ends of the strata into ranges of hills, of which there now remain two remnants, viz., the Mendips, in Somersetshire, and the Ardennes, in Belgium. The Ardennes Hills have many features in common with the Mendips. On the northern flanks of both ranges the palæozoic strata are highly inclined as if tilted up from the same disturbing cause, and both are overlaid by newer strata reposing horizontally on them. From Westphalia to the North of France there is a series of coalfields, the more important being Ruhr, Aix-la-Chapelle, Liège and that of Charleroi, Mons, and Valenciennes, whose longer axes succeed one another along the same line of strike. In all these the coal measures are highly inclined on the south against the Mountain Limestone, while on the north they disappear under newer formations. Westward of Valenciennes no palæozoic strata are exposed on the surface, but the coal measures have been proved to pass beneath the chalk and tertiary to Enquin within 30 miles of Calais, whilst further west the older rocks subtend the chalk. A boring at Calais, however,

proves carboniferous strata at a depth of 1,032 feet from the surface after passing through the chalk.

Passing to a point near the other extremity of the same axis of elevation, a striking resemblance in the geological features is seen. From Milford Haven to Tenby are found old red sandstone and mountain limestone in a contorted condition, resting on which to the northwards is the Pembrokeshire coal-field, considerably disturbed, though not to the same extent as the old red sandstone and mountain limestone; from which it may be inferred that the forces disturbing the strata decreased in proportion to their distance from the line of upheaval. Proceeding eastward along the axis of elevation to the Somersetshire coal-field, the Mendip Hills give evidence of the same tilting and denudation of the older rocks observable in those of the Ardennes range, and on their northern flank are covered by mesozoic strata laid horizontally over the highly inclined coal measures and mountain limestone.

The South Wales coal-field is not hidden by newer strata, but a very large portion of the Somersetshire coal measures is covered by permian, lias, and oolite, and proceeding eastwards these in turn are overlaid by the chalk. The Pennant rock, yielding but few seams of coal, and the associated sandstones, shales, and coal seams above, and also below, with the addition of ironstone, form strong features of resemblance between the coal-field of South Wales and that of Somersetshire.

The similarity in the structure of the rocks of the Mendips and Ardennes, and in the direction of their strike, point to their being due to a common cause, namely, an upheaval of irresistible might and affecting an enormous mass of the earth's crust. The upheaval was too powerful for any opposing force to interrupt, and its continuity under the newer rocks which hide it from view in the South of England, is almost a matter of certainty.

The mountain limestone is continuous throughout the line of elevation, and wherever the older rocks come to the surface, the coal measures show signs of having covered the mountain limestone at the time of disturbance and to have accompanied the latter in its foldings and movements. This fact, taken in conjunction with the unconformability of the permian, enables geologists to fix the age of the axis of elevation, as being after the coal measures and before the permian. The strata of the coal measures were altered from their originally horizontal position by subterranean forces, causing the line of elevation. As the latter proceeded in a slightly irregular, wave-like direction, mostly east and west, the rocks were doubled up or folded into a number of anticlinal and synclinal lines proceeding northwards from the main line of disturbance. The effect of this would be to change what was once a gigantic coal-field into a number of isolated basins separated by ridges of the older rocks, similar to those known to exist. A proof of the series of existing coal-fields having once formed part of a larger, lies in the fact that their edges contain beds of equal thickness with the more central portions. Were they separate coal-fields there would be a thinning out of beds near old lines of shore.

If this reasoning be accurate, then the amount of coal which will be found underlying the newer formations in the South of England will depend entirely on the amount of denudation the coal measures have been subjected to over that area anterior to the deposit of the newer strata. The borings hitherto made point to a southern slope of the surface of the palæozoic rocks in the south of England; the denuded surface can of course give no indication of the dip in the rocks beneath.

Professor Hull shows in a section from Gloucestershire to Oxford that all the newer rocks below the great oolite thin out rapidly to the S. E., the total thickness of the overlying rocks diminishing from 1,880 feet in Gloucestershire to about 600 feet at Oxford.

In 1854–5, a boring on the north side of London passed through tertiary and secondary strata and proved red sandstones, believed to be of palæozoic age, at a depth of 1,114 feet. In 1854–7, a boring at Harwich proved palæozoic rocks at a depth of 1,026 feet, after passing through tertiary strata and the chalk, both the lias and oolite being absent. These borings presented the same order of superposition as that at Calais and in other places in the North of France and Belgium.

The borings alluded to were made for water, but in 1872–5, to test the theory of Mr. Godwin-Austen and Prof. Prestwich, a boring was made near Battle, in Sussex, under the direction of the Sub-Wealden Exploration Committee. It passed through 200 feet of purbeck strata and 1,705 of oolite below, the bottom of which was Oxford clay, and was then abandoned. It proved that the palæozoic rocks did not lie within 1,905 feet of the surface at Battle. In 1886, Sir Edward Watkin, chairman of the Channel Tunnel Company, acting on Professor Boyd-Dawkins's report, which recommended that a bore-hole be made in the neighbourhood of Dover (at the Channel Tunnel works, under the Shakespeare Cliff), gave orders to commence the boring. The site was about 30 miles west of the boring near Calais, which had established the fact that coal measures extended under the newer strata to the French coast line at a depth of 1,092 feet from the surface. After penetrating 500 feet of cretaceous rocks the boring passed through 660 feet of oolitic rocks, when the coal measures were reached, being therefore 1,160 feet from the surface. The boring, after passing only 20 feet further, met with a good seam of coal on the 15th February, 1890. This result, whilst very encouraging to all concerned, has by no means cleared up all the points connected with the hypothesis started by Mr. Godwin-Austen in 1855, but it has clearly established the fact that at any rate one coal-field exists in south-eastern England, where it is covered by the newer strata, and that within a workable depth. This alone is no slight reward for the patient toil and thought of the geologist. It will, doubtless, act as an incentive to other trials along the most likely course of the line of elevation crossing the south of England, between Kent and Somerset, in order to search for other coal-fields or to discover the detached portions of what at one time was one immense coal-field, and is believed now to exist in a more or less denuded state.

Indeed, a company was registered on March the 27th, 1890, with a capital of £2,000 in £1 shares, to search for coal and other minerals in Kent, Surrey, Sussex, and elsewhere in Great Britain.

In this country there is little encouragement offered to private enterprise in searches for coal of the importance attached to that at Dover.

If successful, the landowners in the immediate vicinity derive the greatest benefit, whether they promoted the search or contributed towards its cost or not. They may make what use they like of the information obtained (without reference to the bold spirits who pioneered the venture or those who carried it through), whether by fixing a high royalty price, or by sinking shafts themselves to work the coal so found. In France, where the minerals belong to the State, private enterprise meets with the encouragement which is due to it, and many agricultural districts have through this means been converted into busy mining centres.

When the law relating to royalties has been revised, searches of national importance may be expected to proceed more rapidly in this country, but all things considered, it is perhaps not surprising that so many years should elapse between the expression of Mr. Godwin-Austen's theory and the result to which it has eventually led.

The foregoing observations have reference only to the probabilities of finding coal on the north side of the great axis of elevation, with which we are more

particularly interested, but there is the still further question as to the possibility of finding coal in carboniferous rocks on the south of the great ridge. From the fact of the Mendips being raised after the deposition of the coal measures, the latter in all probability follow on the south side conformably to the beds of mountain limestone.

This has exercised the minds of several men, and led to trials by shafts and borings at positions calculated to prove coal, none of which, however, have met with success. They established the fact that the newer formations attain a greatly increased thickness as compared with those on the north side. To reach the coal measures, shafts must be sunk to a great depth. Then it has been held by some that the culm measures of Devonshire point to a rapid deterioration of the coal measures in that direction, so that the productive measures, if in existence at all on the south of the Mendips, are only so to a limited extent. So far, therefore, as our knowledge extends at present, the search for coal is more likely to be successful on the north than on the south of the line of elevation.

CHAPTER III.

SHAFT-SINKING.

Forms of Shafts—Mode of keeping them truly Vertical during the Sinking—Circumstances calling for consideration in Selecting their Sites—The Tools and Appliances used in Sinking—Timbering as it proceeds—Walling—Tubbing—Machine Drills to Expedite Sinking—Piling through Quicksands—Sinking through Quicksands by Hollow Cylinders of Cast-iron—Poetsch's Freezing System of Sinking through Quicksands—The Kind-Chaudron System of Sinking—Explosives used for Blasting in Sinking.

Shafts may be either rectangular, circular, polygonal or elliptical. In the rectangular and polygonal form, care must be taken to suspend a plumb line from each angle during sinking. In a circular shaft four plumb-lines should be suspended at the extremities of the two diameters, crossing each other at right angles, and in an elliptical shaft four plumb-lines should also be suspended at the extremities of the major and minor axes. Constant care will be required with this plumbing to keep the shaft truly vertical. The circular is the most secure form, though there may be reasons, such as putting in pumps, why an elliptical or rectangular form may be desirable. A number of things must be considered before fixing on the size of the shaft; for instance, what thickness are the seams proposed to be worked? What is the extent of royalty, and on what terms is it secured? Is it probable that adjoining royalties may be afterwards leased on favourable terms? What must the output be, to be profitable, and can labour be had in abundance? What quantity of water will have to be pumped? In all new winnings two shafts are required by law, and their site is a matter requiring much thought. Other things being equal, that site which gives the largest amount of the field to be worked to the rise is preferable. A site which will suit a communication with the railway, tramway, canal, or whatever means of transport there is for the coal, is desirable. If more than one royalty be leased, the winning of the different royalties, and the question of wayleave and out-stroke, may affect the position chosen. It will be only after well considering and balancing these matters that a proper conclusion as to the site can be arrived at.

The tools used in sinking are *hacks*, or *picks*, for loosening the rocks and chipping back the sides. *Shovels* for filling the loosened rock into the kibble. *Wedges* for forcing out the rock by driving them into the joints. *Sledges* are heavy hammers with long handles for use with both hands in driving in the drill, breaking up large pieces of rock, or for striking the wedges. A *hammer* has a short handle, is much lighter than the sledge, and is used with one hand for hitting the head of a drill held in the other. *Drills* are usually made of cast steel, and are bars of different lengths having a cutting and a striking end. A *jumper* is a long drill used with two hands, and without a striker; the operator raising it and letting it fall with considerable force in the hole he is drilling. A *scraper* is a tool for removing the dirt which accumulates in a bore-hole while being drilled. A *swab-stick* is a deal rod bruised at one end, sometimes used for cleaning out the drill-hole. The *bull* is a round bar of iron, with an eye in it, for forcing clay into the interstices of the rock to keep water out of the bore-hole. *Stemmers* or *rammers* for tamping the bore-hole after the charge has been put in. *Cartridges* are cases containing the explosive compound to be inserted

in the bore-hole. The *fuse* is the means by which the cartridge in the bore-hole is fired. It must allow time after being fired and before reaching the cartridge for the men to be drawn away. *Kibbles* or *bowks* are large iron barrel-shaped buckets for the transference of the loosened rock from the pit bottom to the surface. The sinkers also "ride" on it. The *water-kibble* is much the same as the kibble, but it has a valve in the bottom, and is used for sending the water to the surface where the banksman or "waiter-on" pulls a handle communicating with the valve which allows the water to run out; or in another form of water-kibble the valve-spindle projects below the level of the kibble, so that when the engineman lowers it on to the runner the valve is opened by the action, and the water runs out. The *spring hook* is the means of attaching the kibble to the rope, and is shown at Fig. 18.

A pit to be finished 15 feet in diameter must be marked out 17 feet 6 inches to allow for timbering and walling. The sinking of a shaft is most frequently done by contract, and terms of agreement are drawn up between the contractor and manager, or owner, but the latter may, if he wishes, do without the aid of a contractor by paying the sinkers a daily wage, and employing a

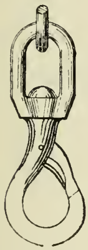
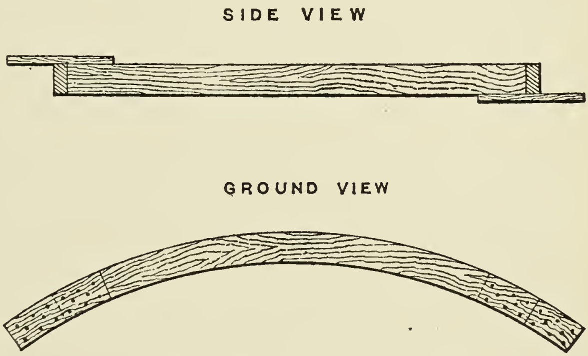


Fig. 18.—Spring Hook.



Figs. 19 and 20.—Curb or Crib.

master-sinker to superintend the operations. The first few yards may be sunk by means of a windlass, after which a steam-engine of suitable size must be got. Two large balks of timber are placed across the pit, which may be afterwards timbered over, except a portion in the centre for the kibbles to pass up and down. On coming to the surface the engineman draws the kibble well up above the level of this opening, and the "waiter-on," or attendant, pushes the "runner" (which is a wide trolley-shaped carriage running on rails) into position, thereby covering the pit top and protecting the sinkers, whilst the engineman lowers the kibble on to it. It is then detached, an empty kibble which has been standing ready on the runner is attached to the rope, the signal given to the engineman to lift, and this being done the "runner" is pushed out with the full kibble on it, leaving the opening clear for the descent of the empty kibble. It is usual only to use one kibble in a sinking pit on account of the danger from collision which would arise if two kibbles were used.

After the first 6 feet of sinking has been done, which will most likely be through soil or clay, *curbs* or *cribs* must be put in. These are segments of wood (see Figs. 19 and 20) cut out to the circle of the pit, and are generally 6 inches square and made of oak or elm, the former being preferable. The joints must radiate truly from the centre of the shaft, and cleats, as shown in the sketches, secured to them at the surface in order that the joints may be brought into proper contact when the curb is fixed in the pit. Sometimes a scarfed joint is made between

the segments or curbs, but this is not so good a plan as the straight joints with cleats. The crib being fixed in its position in the pit, *backing deals* an inch thick and 9 feet long are then passed down behind the curb to half its thickness. The backing deals must be close together if the ground be bad. A second curb is now sent down and put together on No. 1 curb, then raised 3 feet (or less if the ground is bad and it is thought desirable to have them closer together); it is kept in position by a few props, called punch props, placed under it and resting on No. 1 curb. A third crib is sent down and put together on No. 2 curb and raised 3 feet where it is secured by punch props, and a fourth curb put together on No. 3 and raised will bring it to the top of the backing deals; it is secured there by punch props. The top of the backing deals will be 3 feet above the surface level, and will allow room to tip the rock and rubbish coming up. *Stringing deals* are next fastened to the inside of the curbs and to the balks of timber across the pit top, so as to keep all firmly in position. Another 6 feet of ground is then taken out with care so as to leave solid ground under the last curb placed; in other words the sinking is reduced a foot until the 6 feet is taken out, and then the ground must be removed sufficiently to place another curb truly in its bed, which is done as before, and then the ground shorn back up to the next curb 6 feet up and the backing deals 6 feet long placed from the back of one row of cribs to the other. Another curb is sent down, put together and raised 3 feet, and secured there by punch props. The sinking is then resumed and this plan of taking out 6 feet and then timbering it continued until the stone-head or hard rock is met with, care being taken to continue the stringing planks downwards to secure the cribs. Sometimes the nature of the ground will not admit of 6 feet of sinking being taken out without being secured, and in that case the work must be done in shorter stages.

On reaching the hard rock the size of the pit must be reduced to allow of a firm support to remain under the curbs, and after sinking in it till a good sound rock is found, it will be necessary to prepare this bed to take the walling curb. The diameter of the shaft must be increased to say 17 feet 9 inches, which is 3 inches larger than before. The bed must be correctly prepared truly level by picks and without explosives, which would produce cracks in the rock. The *walling curb* may be of iron or oak timber and must be 13 inches or more in the bed; it is made in segments, and requires great care in fixing. Half-inch fir sheathing is first placed on the bed prepared in the stone, and the curb laid on the sheathing. Two inches of fir backing is placed between it and the shaft sides and firmly wedged, care being taken to keep the centre of the curb correct. If iron curbs are used, oak sheathing is placed between the joints of the segments. The walling may now proceed, bricks shaped to the curve of the pit being generally used. The mortar should be of the best and of a slightly hydraulic character. Sometimes the permanent shaft buntons are walled in as the work proceeds, so as to save cutting the pit sides afterwards.

The thickness of walling required will depend on circumstances, and may vary from 9 inches to 18 inches; for a 15-foot pit, probably 13 inches would be a suitable size. The *cradle* now comes into use. It is a circular platform, when used in a circular pit, of planking 2″ or 3″ thick, nailed to stouter pieces of timber, Through these larger pieces of timber bolts with rings pass and are secured below by nuts. To prevent canting it should be hung by six bridle chains to the rope. The cradle should be of such a size as to leave about 3 inches of space between it and the finished size of the shaft, and is moved up and down by means of a strong rope attached to a crab or engine at the surface.

As the walling proceeds, great care must be taken in removing the timber above, and the space between the walling and the rock should be rammed with concrete or clay. The walling may be continued up above the surface level 5 to 15 feet as may be most desirable.

Should water now be met with, it will be necessary to make provision for its removal. If it can be done by winding with kibbles this will be most economical, but if more than say 10–200 gallon barrels an hour be got, pumps must be put in. These are usually suspended by ropes or chains from winches on the surface to admit of their extension as the sinking increases.

It will be necessary to put in ventilation boxes or pipes, and to command a supply of air by connecting them with a little fan on the surface or some chimney which will create a draft. Round iron pipes 15 inches in diameter with a little fan worked by one of the engines will generally supply a sufficient quantity of air, but if not the shaft must be bratticed. The rocks met with below may be very hard, and if rock drills should be used in passing through it worked by compressed air, the exhaust and jets taken from the air pipe may enable bratticing to be dispensed with.

On resuming the sinking beneath the walling curb the pit is sunk in a line with the inside of the curb for about 3 feet, and then gradually enlarged to its proper size. On reaching a suitable stone, the walling is brought up from a wedging crib placed on it, and care must be taken in approaching the upper wedging crib (upon which the first piece or section of walling rests) to shear back the rock and join the walling under it without disturbing the wedging crib. This will be effected by removing the rock from under it (between the point where the shaft was set out to its full size and the upper wedging crib), through a small space and then completing the walling up through that space against the wedging crib. Then the rock may similarly be removed through another small space and the walling brought up through it to the wedging crib, and so on till the whole circle of the pit is completed. Or the first length of walling may be secured by fixing a number of iron rods immediately below the crib, the rods being driven into holes bored in the rock.

Great depths are frequently attained without using guides of any description for steadying the kibble in its ascent and descent. In a shaft of large diameter, say 14 feet and upwards, with plenty of space, steady hauling, and the exercise of care by the sinkers in the bottom not to load the kibble too high, and to perfectly steady it when raised a foot or two from the bottom before signalling it away, there is little danger in proceeding thus.

In smaller shafts much obstructed with pumps, guides of wood or wire ropes should be used. These will tend to steady the kibble, and prevent the winding rope from rotating. The rotating of a new winding rope is anything but pleasant to those riding in a sinking shaft, and may possibly cause an accident through giddiness.

If the shaft be fitted with wooden or iron conductors as the sinking proceeds, these may be used to guide a slide carrier or rider. It consists of a horizontal cross-bar, the ends of which fit the guides. This is carried by inclined struts to a circular piece fitting loosely over the winding rope. A buffer-catch is secured to the rope at its lower extremity, which fits into the circular portion of the slide-carrier, and raises it in its ascent.

The guides at their lower ends have stoppers, so as to arrest the carrier in its descent, and hold it there whilst the buffer-catch becomes disengaged from the rider, and the kibble is free to descend without guides to the bottom of the shaft. Similarly it ascends unguided again until it reaches the carrier, which is afterwards lifted up with it.

Where wooden or iron guides are not available, wire ropes may be used as guides for the carrier. Weights are attached to their ends in the shaft through a balk stretched across the shaft; the balk also serves to arrest the further descent of the carrier.

The guide ropes are wound on the drums of steam or hand crabs on the surface, and pass over pulleys at the shaft there, so as to admit of their being easily lowered; they are long enough to reach the expected depth of the sinking.

The objection to this system is that the balk in the shaft requires frequent change. Mr. W. Galloway has patented a great improvement of this system, in which the ends of the guide ropes are secured to the cradle, beyond which the kibble descends unguided through a door in the cradle.

A *ring-crib* (Fig. 21) is frequently used in wet pits. It consists of a crib hollowed out in the shape of a gutter, and is built into the shaft, the first two or three courses of brickwork upon it being inset or shorn back, so as to leave a portion of the crib in which the channel is cut exposed as shown in the sketch. The water which trickles down the sides of the shaft runs into this ring-crib, and from thence it is conveyed down the shaft by means of a "waste pipe," one end of which is let obliquely through a hole in the crib to the bottom of the channel, and the other is placed over the cistern, from which the pump takes its water. Sometimes a wedging crib is used as a "ring-crib" (see Figs. 22 and 23).

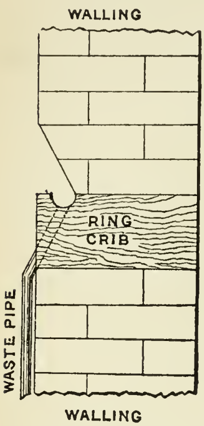


Fig. 21.—Ring Crib.

Frequently large quantities of water are found in the hard rocks, and if circumstances admit, these should be tubbed back with cast-iron tubbing. If, however, the bed of rock on which we are able to place the bottom part of this tubbing is near a seam of coal, or even if it is some distance away, but in communication with it by fissures, or the rocks between are not impervious to the passage of water, there will be no advantage derived from the tubbing, because the water will find its way down to the seam, and remain as much a burden to the colliery as if the tubbing had not been put in. Assuming an impervious bed of rock to be available, and that there is a large quantity of water below the walling, the sinking would be continued from the last wedging crib at the reduced diameter of 15 feet for a few feet, so as to leave a support under the wedging crib, and then gradually enlarged to a size suitable to take the tubbing, and on approaching

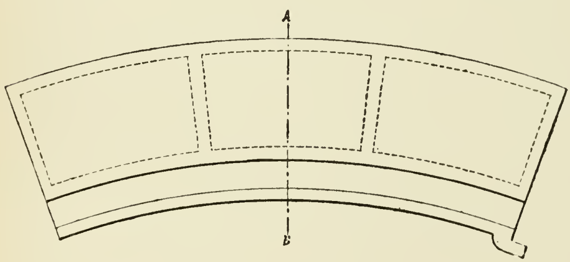


Fig. 22.—Combined Wedging and Ring Crib.

SECTION THRO' A.B.

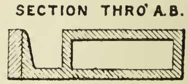


Fig. 23.

the impervious rock alluded to, the shaft should be again reduced to a diameter of 15 feet, and the sinking carried a few feet, say 6, into it, to serve as a sump, and allow of the water kibbles being used whilst efforts are directed to the tubbing operations. Explosives should be avoided in sinking past the point where the wedging curb will be fixed.

A bed should be carefully prepared at the commencement of the impervious rock for the wedging crib, or cribs (for often two are laid), which is somewhat similar to the walling curb, but of cast iron about 6 inches deep, and 13 inches in the bed. The pit is shorn back so as to admit of the wedging crib being placed, and also leave a small annular space round it; the bed for the reception of the wedging curb must be dressed with hacks perfectly smooth and level. The

curb is then laid and securely wedged, the space behind having been filled with fir sheathing, and behind that again moss or oakum. Sometimes both the single and double cribs are provided with escape valves to release the air as it escapes from the back of the tubbing. The segments of *metal tubbing* (see Figs. 24 and 25), having first of all been tested by sounding them all over with a hammer and punch on the surface, are next to be proceeded with. These segments are cast with a smooth inner surface, and are flanged so as to fit into each other, a hole being left in the centre of each to allow the water to run out whilst building them up, and also for convenience in sending down the pit. Pitch-pine sheathing is first laid on the wedging crib, and then the segments are fitted round it, 10 or 12 forming the circle, and they are usually 2 or 3 feet high. The ground is

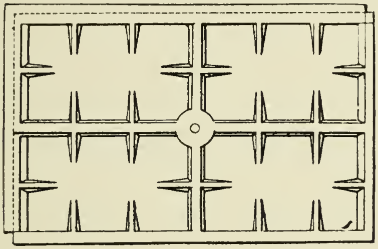


Fig. 24.—Elevation.

Fig. 25.—Cross Section.

Segment of Metal Tubbing.

shorn back near the crib where required as the tubbing is built up. The thickness of metal in the tubbing will depend upon the height the tubbing has to be carried, and varies from $\frac{3}{4}$ of an inch to $1\frac{1}{2}$ inches. Mr. Greenwell gives the following formula for estimating the thickness of metal tubbing, the height of the segment being 2 feet.

Let $x =$ the required thickness in feet.
$P =$ the pressure or vertical depth in feet.
$D =$ the diameter of the pit, also in feet.

$$\text{Then } x = \cdot 03 + \frac{P \times D}{50{,}000}$$

so that if we had 60 fathoms of water-bearing strata to tub through in a 15-foot pit, we have

$$\cdot 03 + \frac{360 \times 15}{50{,}000} = \cdot 138 \text{ of a foot} = 1 \cdot 656 \text{ inch.}$$

In practice the thickness of tubbing is generally reduced every few feet upwards. Sometimes it is necessary to cover the tubbing with tar or wood lining, to help preserve it; if the shaft is afterwards to become an upcast, ventilated by a furnace, a brick lining over the tubbing will be necessary. But this would not be placed until the building of the tubbing in the shaft was quite completed. A second course of segments is now proceeded with, a sheathing of pitch pine having been laid all round on the top of the first, to allow of wedging when all is built up, and care must be taken in the building to break the joints of the tubbing. This method is continued until approaching the rock left to support the wedging crib above, a part of which must be shorn back to allow of the tubbing fitting in truly under the wedging crib. All the vertical joints in going upwards should have strips of wood laid behind them an inch thick, and about

6 inches broad, and a wedge-shaped piece driven behind, to force the segments well together at the joints, and the space behind the tubbing should be filled up with concrete. When all the tubbing has been thus placed in position, the important operation of wedging the joints is commenced, from the bottom upwards, leaving the centre holes till last. The plugging of these is upwards also, and requires skill and care if much water is coming through them.

Sometimes the tubbing, when carried above the water-bearing strata, is left open-topped, but this does not allow of such good wedging as the close-topped tubbing. Sometimes it is necessary with close-topped tubbing to put a pipe into one of the upper segments, and either allow it to remain open, and the water to run constantly down the pit, or to continue the pipe up the pit above the level of the water behind the tubbing. This allows a vent for the air from behind, which, when no provision was made for its removal, has been known to do considerable damage. The segments should have proper pieces cast on them to which to fasten the buntons, when the pit is fitted up with guides.

It is often a matter of the utmost importance to those connected with a new sinking, that the shafts should be sunk as expeditiously as possible. Where the seam required to be worked lies at a great depth from the surface, and the shafts are to be of large size, some kind of machine-rock drill, worked by compressed air, will be necessary to bore the shot-holes in the bottom rapidly. At the Harris's Navigation Pits in South Wales, different forms of machine drills were used to expedite the work. The shafts forming the colliery are each 17 feet in diameter inside the walling, and are sunk to a depth of 760 yards.

A large diamond-boring machine was at first used in hard rock, the action of the drill being similar to that of the diamond-drill when used for prospecting purposes, and described in the previous chapter. In this case the machine consisted of 8 drills, each drill being complete in itself and driven by compressed air, while the whole was attached to four beams fixed to a centre-piece. The engine was attached to the frame and lowered down the shaft, the motive power being conveyed down a pipe, the bottom of which was a flexible hose. The supply-water for the drills was taken down the pit in a pipe of smaller diameter than the drills, and was raised by the ordinary means of removing water from the pit bottom. The drills were capable of adjustment on the beams, and could be placed obliquely to any extent parallel with the face of the beams, each, however, remaining under separate control so as to be worked or stopped as required. About 30 holes were drilled, 8 proceeding simultaneously in the bottom from 3 to 5 feet deep, and also as an experiment deep holes from 15 to 30 feet were bored and blasted in sections. Whether it gave the most effective shot-holes or not, it was necessary to keep the long holes vertical, or their lower extremities passed beyond the line of the shaft. The short holes made frequent changes necessary, and resulted in the loss of diamonds in the drill crowns, causing the process to be abandoned. The Ingersoll rock-drill, which is fully described in Chapter XIV. of this work, was then applied to bore the shot-holes, and this it did very effectively.

In sinking through the surface beds, quicksands are occasionally met with which tax the energy and patience of those engaged in the sinking operations. The old method of sinking through quicksands was by piling, which requires the shaft at the commencement of the quicksand to be very large in diameter where there is a considerable depth of sand.

It is shown at Fig. 27 and is carried out as follows :—The piles are, say, 15 feet long, 6 inches wide, 3 inches thick, pointed and shod with iron, their edges being bevelled to allow a true fit into each other; the head should be hooped for the purpose of preserving it in driving. The curbs are 6 inches square, the piles 3 inches thick, so that each course of piling put in will reduce the size of pit

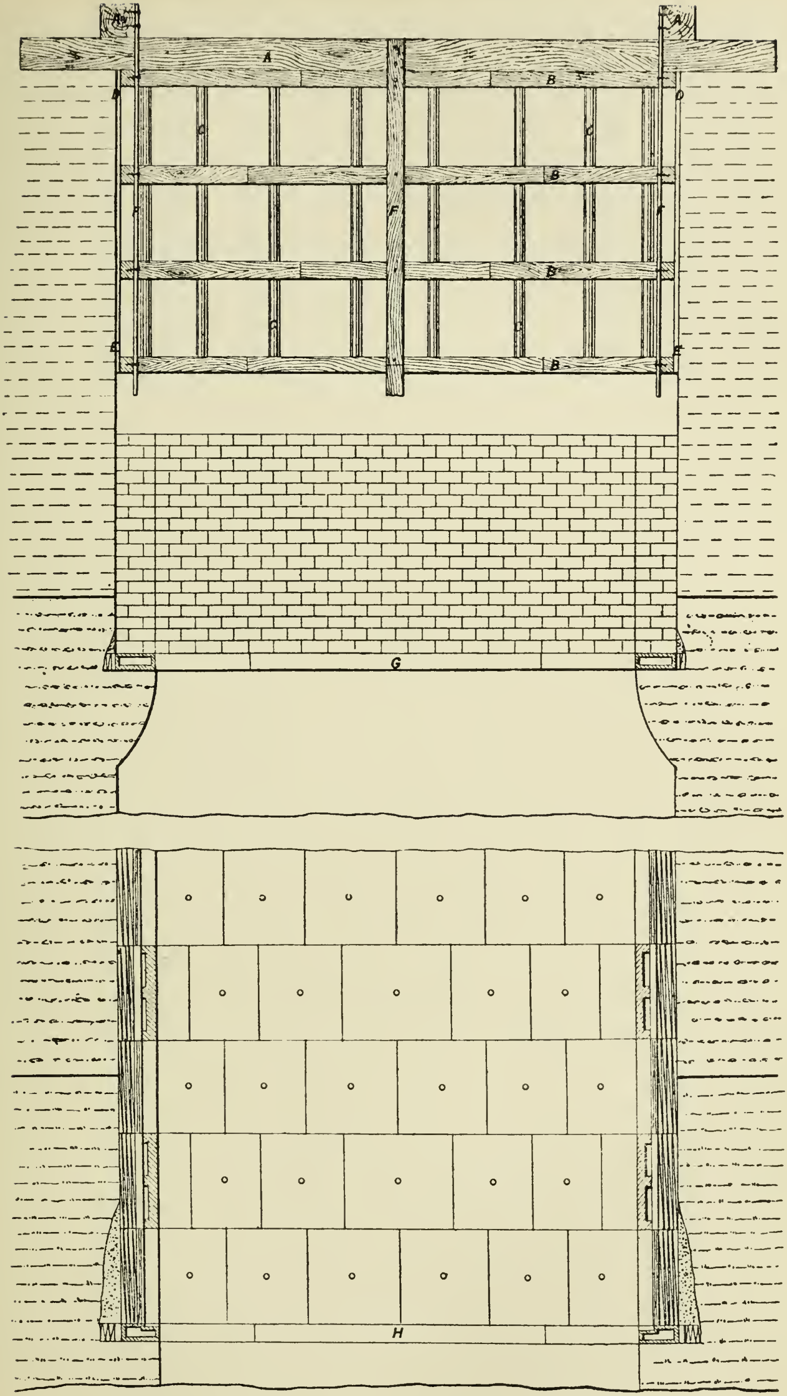


Fig. 26.—Timber, Walling, and Tubbing in a Sinking Shaft.

A. Balks laid across the top of the shaft. B. Timbering curbs. C. Punch props. D E. Backing deals, shown in section but otherwise omitted for the sake of clearness. F. Stringing deals. G. Walling curb, with the walling shown above it. H. Hollow cast-iron wedging curb with cast-iron tubbing resting on it.

18 inches. With 15 feet length of piles, a fresh course is required every 12 feet, so that the depth of the quicksand in feet divided by 12 and the result multiplied by $1\frac{1}{2}$, gives the reduction in size. The reduction in a quicksand of 84 feet would be $\frac{84}{12} = 7$, and $7 \times 1\frac{1}{2} = 10\frac{1}{2}$ feet; if the diameter of the pit is to be 17 feet 6 inches, to allow of a 15-foot net size, it would require to be 10 feet 6 inches + 17 feet 6 inches = 28 feet in diameter at the top of the quicksand.

It will be necessary on reaching the quicksand to put an additional crib-bed 6 inches less in diameter than the diameter of the crib last put in; it must be concentric with it, and allow of the piles being driven between the two. Care must be taken to drive them down vertically, and after getting them down a few feet, as much of the quicksand as is practicable is taken out and a crib put in. Again the piles are driven down a few feet, the quicksand removed and a crib put in. These operations are continued until the piles are fully down, and the quicksand removed to within 3 feet of the bottom of them, a crib laid to support them and another laid inside and concentric to it, 18 inches less in diameter, to allow the next course of piles to be driven in the annular space between the two. The same operation of driving, excavating and laying cribs is again gone through. When within 3 feet of the foot of these piles another curb 18 inches less in diameter is put in to allow of another course of piles, and so on till the stone head is reached, when the wedging curb is laid and the walling or tubbing run up as expeditiously as possible through the treacherous ground.

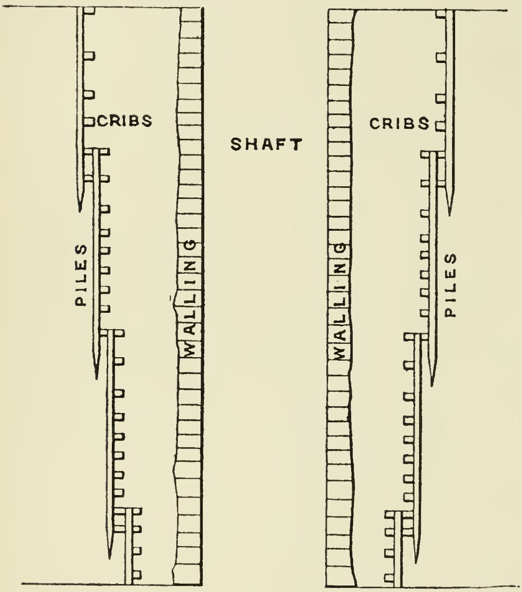


Fig 27.—Piling through Quicksand.

Another method of getting through quicksands, consists in sinking by means of hollow cylinders of cast iron, pressed down by heavy weights piled on the top, but sometimes there is considerable difficulty in keeping the cylinders in a vertical position, especially if large boulders are met with.

An ingenious and efficient method of sinking through quicksand is Poetsch's Freezing System, whereby the quicksand is transformed into a solid mass. The quicksand in its changed and solid form is then sunk through in the ordinary manner.

A refrigerating liquid, consisting of a solution of chloride of calcium, is produced on the surface by means of proper machinery.* Through tubes this liquid is conveyed into the shaft required to be sunk through the quicksand. A zone of quicksand must be solidified round the shaft and downwards sufficiently far to form a wall or barrier all round the part to be excavated, and sufficiently thick to resist the surrounding pressure.

* See Transactions, South Wales Institute of Mining Engineers, vol. xv. pp. 143—151.

The thickness of this wall is determined beforehand by taking into account the depth at which the quicksand occurs, and the thickness of the quicksand itself.

Figs. 28 & 29 show the principle of applying Poetsch's sinking process to a quicksand 20 feet thick. The tubes A A are of wrought iron 8 inches in diameter, provided at their lower extremity with a circular blade D 8 inches high and slightly tapered in form. These tubes are sunk vertically at distances apart varying from 1 foot to 4 feet. Upon their reaching the solid rock below the quicksand, the lower end of each tube is closed with a leaden plug C, fitting into the tapered end piece and covered with several alternate layers of cement and pitch E to ensure the closure being water-tight. When each of the large tubes A A has been treated in this way, an inner tube B, $2\frac{1}{8}$ inches in diameter, is inserted within the larger tube, and is provided at its lower extremity with an opening F. The large tubes are flanged at G, and by this means attached to a cast-iron branch with three outlets and flanges H, H and J. The outside tubes are all connected by means of the side flanges H, H, whilst the flange at J receives the inner descending tube B.

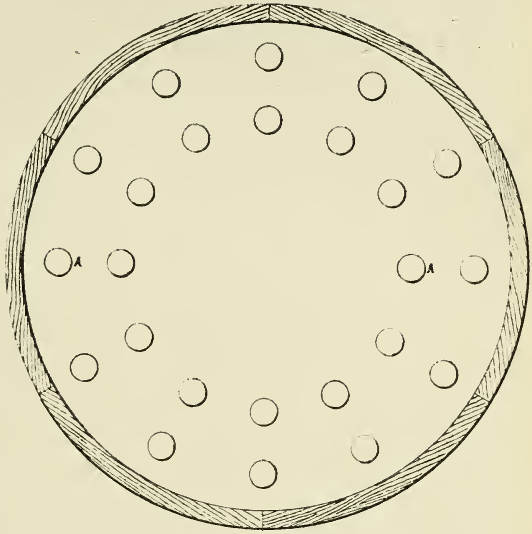


Fig. 28.—Poetsch's Sinking Process.

The course of the liquid, as shown by the arrows, is down the pipe M and through the inner central tubes B, returning in the annular space between the tubes A and B and ascending the pipe L. The whole system of pipes down which the liquid is conveyed is controlled by the valves K K. After ascending the pipe L the liquid again reaches the refrigerating apparatus. The quicksand in contact with the tubes A A thus becomes frozen into a solid mass. The solution is injected by means of a pump into the descending column M.

The frozen mass is removed by picks, pointed hammers and crowbars, without the use of explosive. The wall formed by this process round the shafts is about 5 feet thick, and will resist all external pressure until the shaft is permanently secured.

The Kind-Chaudron System is perhaps the best for sinking where there are very heavy feeders of water to contend with.

Fig. 30 shows the method adopted.*

The sinkers employed at the shaft are four or five in number, and stand on a working floor about 6 yards below the surface. The shaft is about 4 feet more in diameter over the first 6 yards than below, where it becomes the finished size. The first operation consists of boring out, by machinery, a cylindrical hole of about $4\frac{1}{2}$ or 5 feet in diameter. This hole is afterwards enlarged by a second, or if the pit is large, by a third operation. The first operation is kept at least 33 feet in advance of the second.

* See Transactions, North of England Institute of Mining Engineers, vol. XX. pp. 187—202.

The cutting of the material is by the same kind of means in both or all stages (the central and enlarging), but the removal of the broken ground is different. In each case the cutting tool (Figs. 31–37) consists of a horizontal wrought-iron bar, to the under side of which are attached steeled teeth. The arrangement of these teeth is such that as the bar revolves round the central axis of the pit, each tooth in falling with the bar through the length of stroke used (from 10 to 20 inches) cuts for itself an annular portion of the bottom of the shaft. The large and small cutters, or *trépans*, are lifted and turned by the same

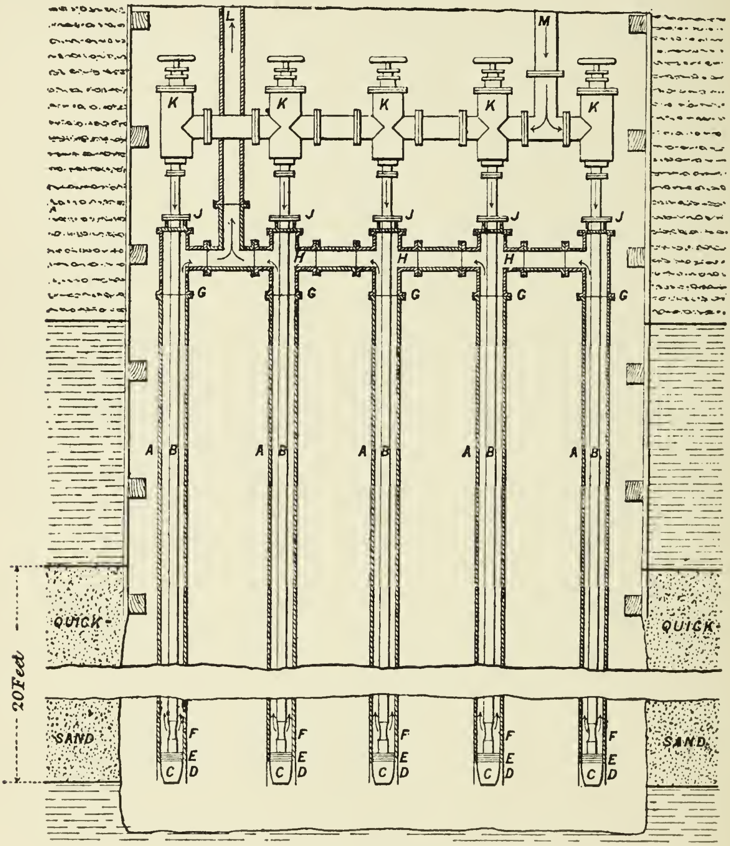


Fig. 29.—Poetsch's Sinking Process.

rods, which are made of pine about 8 inches square and 20 yards long, and connected by male and female screws. Only one *trépan* can be used at a time. In the sinking of a shaft at Maurage, near Mons, a simple lever was placed at the surface level, one end of which was attached to the rods by a strong flat chain, whilst near the other end it had a direct connection with the piston rod of a steam engine. The single cylinder was $39\frac{3}{8}$ inches in diameter, with a 40-inch stroke, and was placed vertically below the beam. The lift of the rods was effected by admitting steam to the cylinder above the piston, depressing that end of the lever and raising the rods and cutter, which then fell by their own weight. The lever or striking beam was 23 feet long, 11 feet on the side of the rods and 12 feet on the side of the engine, and was composed of two

logs of wood, one placed over the other, strengthened on each side by a stout plate of iron. Beneath the suspension chain is a lengthening screw, below

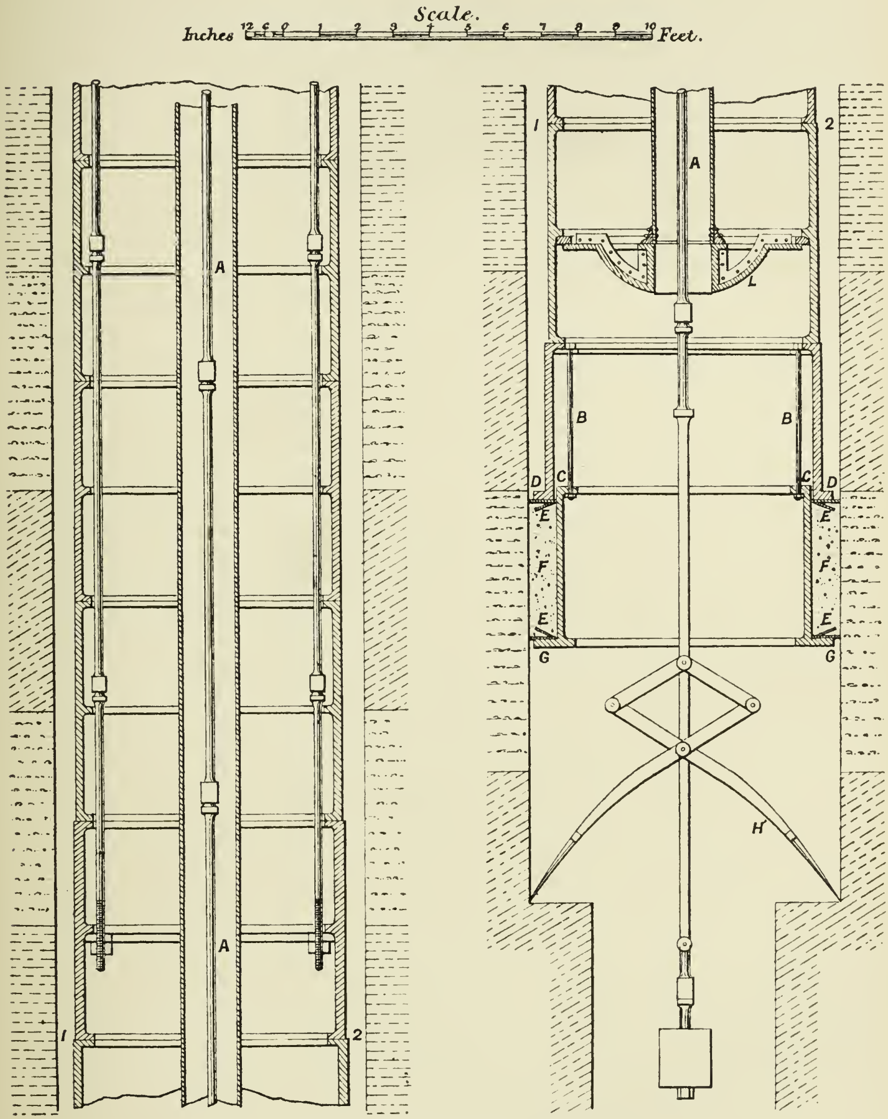


Fig. 30.—Kind-Chaudron System of Shaft Sinking.

which is a very strong swivel, by means of which the rotating movement is given to the rods and cutter.

The top length of rod has eyes for the insertion of cross bars. The workmen, standing on the wooden flap doors which close the shaft (except a central hole for the rods to work through) at the level of the working floor, turn the rods by means of the cross bars at each stroke. The smaller *trépan* (Figs. 34–37),

requires modification in its construction, according to the nature of the material to be cut. If soft, the bar to which the teeth are attached is suspended by a fork of wrought iron, but for hard rock it is forged in a single piece and weighs

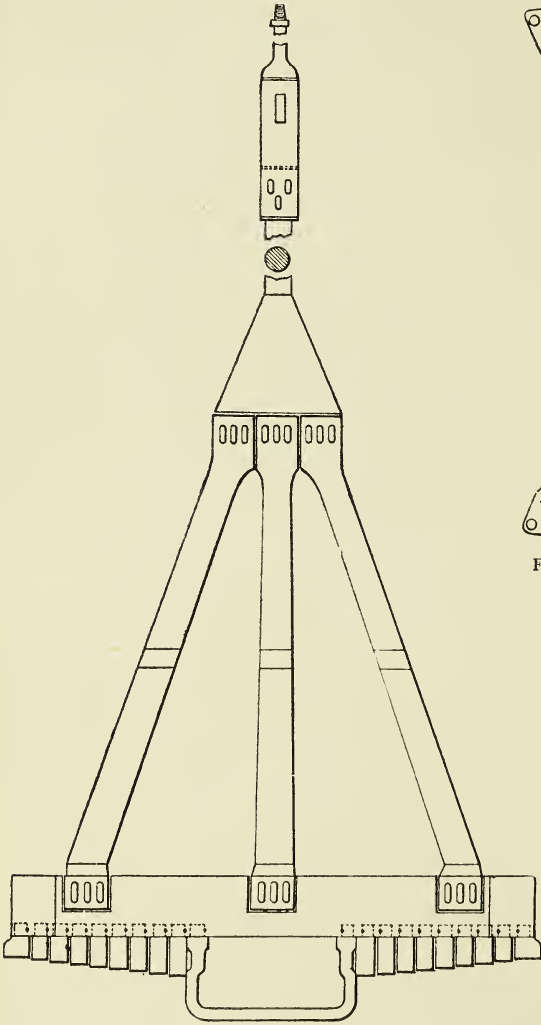


Fig. 31.

Fig. 32.

Fig. 33.

KIND-CHAUDRON SYSTEM—LARGE TRÉPAN

about 8 tons. In ordinary ground this cutter advances about 8 feet per day. The teeth are well steeled, fit into sockets in the main bar, and are further secured by a pin easily removed when the teeth require sharpening or renewing.

The cutter is driven about 9 or 10 strokes a minute usually, but sometimes more, and after being some hours at work, it is raised by a small capstan-engine,

with a flat hemp rope of $14\frac{1}{4}$ inches wide by $2\frac{3}{8}$ inches thick. The rods require unscrewing (as in the ordinary manner of boring rods) as the cutter is being withdrawn. To clear the whole of the cut material a sheet-iron cylinder 6 feet long, with two valves in the bottom, is lowered and raised by the rods.

The larger *trépan* (Figs. 31–33) weighs about 16 tons and has a bar of wrought iron, to a portion of which teeth are attached as in the smaller *trépan*. The

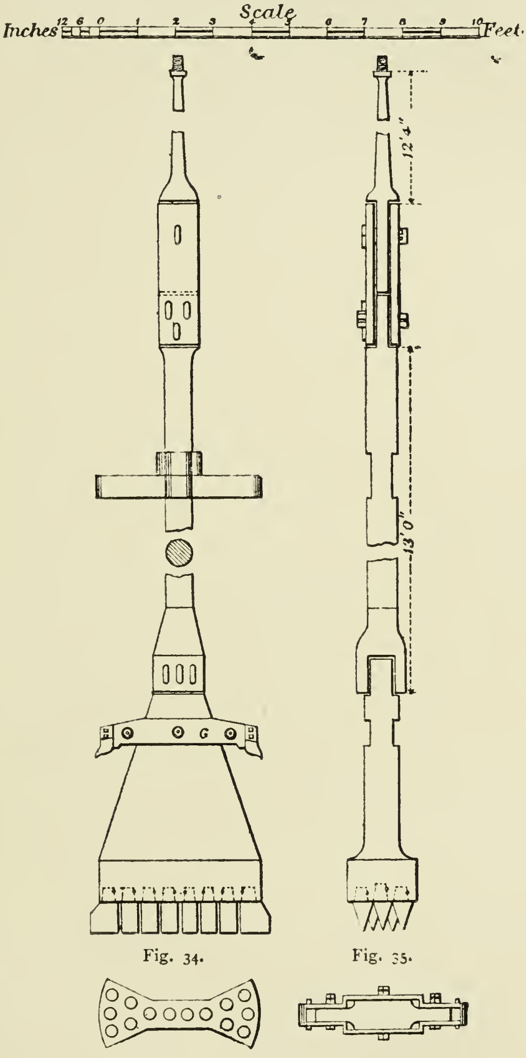


Fig. 34. Fig. 35.

Fig. 36. Fig. 37.

KIND-CHAUDRON SYSTEM—SMALL TRÉPAN.

teeth are fixed on that portion of the bar which exceeds the diameter of the hole cut at the first operation. The large *trépan* is guided below by a cradle of iron bars fitting loosely within the smaller diameter.

The arrangement of teeth is such as to cause them to cut a sloping surface at the bottom of the shaft so as to ensure the cut material to roll into the

smaller pit, where they drop into a sheet-iron bucket previously lowered into it. The rate of progress varies from 3 feet per day in ordinary ground to 1 foot per day in hard rock.

To obviate the excessive vibration which would otherwise be imparted to the rods by tools of such a weight, a special joint, called a slide piece, of great strength, is applied.

To maintain the boring rods in a vertical position throughout their stroke, guides are attached to the upper part of the implement. In the smaller cutter these consist of two strong iron bars set at right angles (G, Fig. 34), having teeth fixed at their extremity, which slightly enlarge and, at the same time, smooth down the sides of the hole. For the large *trépan*, one of the cross pieces is rigid and the other, at right angles, is hinged on both sides of the main rod in such manner that it can be lowered or raised by ropes during the shifting of tools, through a small opening in the working floor. The guide, when in position, forms a fixed cross, through the central opening of which the cutter rod slides freely up and down.

The pit having been sunk through the water-bearing strata in this way requires tubbing. In this process the lowermost ring, like all the upper portion, is cast in one piece. The lower flange G, Fig. 30, is turned outwards, its upper flange C inwards, and it rests on a bed in water-tight ground below the water-bearing rocks. Upon the lower flange and all round the ring a wall of well-selected moss, F, is packed tightly against it and secured in its position by a net placed at the back of it. To assist in forcing the moss against the side of the shaft, small sheet-iron springs, E E, are placed above and below, the effect of which is to give the pressure a definite direction. On the moss cushion rests the next ring, D. Its bottom flange is turned outwards, the top one inwards, and it is of such a size as to slide down outside the bottom ring, when the moss is sufficiently pressed down by the weight, and upon this sliding ring the ordinary tubbing rings are built. Each flange is truly planed, and between the flanges a ring of sheet-lead, $\frac{1}{8}$th of an inch thick, is laid. After screwing up the bolts the lead is beaten in on both sides with hammer and chisel. Each ring of tubbing is from $4\frac{1}{2}$ to 5 feet high, is of extra thickness, and tested on the surface by hydraulic pressure. The bottom simple ring is $2\frac{5}{8}$ inches thick, and weighs $11\frac{3}{4}$ tons for a 14-foot pit. The upper rings are gradually lighter.

To facilitate the gradual lowering of the enormous weight of the tubbing, by means of six rods and screws used for this purpose, a diaphragm or false bottom, L, is attached by screw-bolts at a point near the bottom of the tubbing, and this causes it to float on the water. A central equilibrium tube, A, passes up the shaft from the false bottom, and through cocks, placed at intervals, allows of water being poured into the middle of the tubbing in sufficient quantity as may be required to help its descent. By this means no greater weight than 40 tons rests on the suspension rods.

The bottom ring or moss-box is suspended by light rods, B, to the flange of an upper ring, and is lowered into its position on its seat or bed. The weight of tubbing then bears on the moss and squeezes it down and against the sides of the shaft so as to form a thoroughly water-tight joint.

The annular space between the rings and the shaft is filled in with concrete and allowed to consolidate before the water is drawn out of the pit. The success of the undertaking to a large extent depends on the perfection with which the seat of the moss box is cut and smoothed, and to ensure its suitable condition, a gigantic pair of pincers, H, with arms on the principle of a lazy-tongs, is lowered with and underneath the whole of the tubbing by means of a rod passing up through the central tube. By working the rod up and down, the ends of this tool may be made either to expand to the full size of the shaft, or brought closely together and thus pick up small pieces of stone or other material which may be

lying on the bed of the shaft; when in its contracted form it may be passed into the central shaft to be out of the way. After the concrete has set, the water is pumped out, the false bottom taken off by unscrewing the bolts which attached it to a flange, and the moss box is examined. For safety, a lower seating is cut and prepared in the rock a few feet deeper, a wedging curb put in by hand in segments, and the tubbing built up on it to the moss box, against which it is securely wedged. The shaft being now free from water may be sunk deeper by ordinary methods.

The explosives used for blasting in sinking are:—gunpowder, which is a compound of sulphur, saltpetre, and charcoal. It is useful for rending operations, and when the rock is not hard and is also free from water it may be used to much advantage. Dynamite is a "shattering" agent, and contains 75 per cent. of nitro-glycerine. When in a frozen state it explodes with difficulty. It requires to be exploded by detonation to get the best result, and it is a very useful agent in a wet pit and in a hard rock as the water does not injure it; indeed, frequently the holes are simply tamped with water. Explosives are more fully described in Chapter XIV. of this work.

As questions are sometimes given at the examinations, having reference to the cubical contents obtained from sinking shafts, the following example is given and worked out in order to show candidates how to do similar calculations.

> *Question* 1.—A pit is sunk 17 feet 6 inches in diameter, and walled with good bricks 13 inches in the bed, 6 inches deep by 12 inches long inside, but more at the back—being moulded to suit the circle of the pit—the diameter of the shaft when the walling is finished being 15 feet in the clear. The pit is 100 fathoms deep.—How many cubic feet of excavation would be taken out, and assuming 14 cubic feet of it to weigh a ton, state the total weight? Also, if walled from top to bottom, how many bricks of the above dimensions would be required, and how much would they cost at £5 per thousand?

Here we have to get the area of a circle whose diameter is 17 feet 6 inches, and to multiply it by the depth of the pit in feet to get the cubical contents.

$$17{\cdot}5 \times 17{\cdot}5 \times {\cdot}7854 \times 600 = 144{,}317 \text{ cubic feet,}$$

$$\text{and } \frac{144{,}317}{14} = 10{,}308{\cdot}38 \text{ tons.}$$

To find the number of bricks we must find the circumference of a circle whose diameter is 15 feet; $15 \times 3{\cdot}14159 = 47{\cdot}124$, and if we allow $\frac{1}{4}$ of an inch for mortar at the joints we should require $\frac{47{\cdot}124 \times 12}{12{\cdot}25} = 46{\cdot}16$, the number of bricks which we should require for one ring; allowing $\frac{1}{4}$ of an inch for the horizontal joints the pit would have $\frac{100 \times 6 \times 12}{6\frac{1}{4}} = 1{,}152$ rings. Therefore $1{,}152 \times 46{\cdot}16 = 53{,}176{\cdot}32$, the number of bricks required, and $\frac{53{,}176{\cdot}32 \times 100}{1{,}000} = 5{,}317{\cdot}632$ shillings $=$ £265 17*s*. 7*d*. as the cost of the bricks.

CHAPTER IV.

FITTING UP THE SHAFT AND SURFACE ARRANGEMENTS.

Arrangement of Pit Bottom for Small and Large Trams—Shaft Gates—Conductors—Buntons—Keeps—Pit Cages—Safety Cages—Detaching Hooks—Pit Head-gear—Pulleys—Ropes—Capping Round and Flat Ropes—Observations for Users of Ropes—Tables of different qualities of Round and Flat Ropes and of Chains—Method of Splicing Ropes—Shaft Signals—Pit Stage—Tipplers—Screens and under Railways—Winding Engines—Conical and Spiral Drums—Steam-brake to prevent over-winding—Counterbalancing the Load in Shaft—Rules for Winding Engines—Calculations of Sizes required under given Conditions—Questions and Answers on Steam and Steam-engines—Systems of Winding Coal up Shafts without using Drums.

The shaft bottom and roadways, for some distance, leading from the pit bottom are generally arched. Where small trams are to be used the space round about the shaft bottom is usually laid with flat sheet-iron for facilitating the operations.

Where large trams are used rails are laid leading to each cage from opposite directions. This allows of the empty trams being propelled from the cage on one side as the loaded ones enter it at the other.

Where flat sheets are used, they allow of light full tubs, or the lighter empties, being quickly turned in any direction without having to follow a particular course.

The pit is sunk a few feet below the level of the flat sheets to form a sump, and into this the water (if any) drains; from thence it is raised direct by the pumps placed in the shaft or conveyed elsewhere to be dealt with. The pit bottom is arranged so that the loaded tubs are pushed towards the cage down a slightly falling road, and the empty tubs pass out of the cage on the opposite side of the shaft.

The top of the pit and any intermediate loading places between the top and bottom, are provided with gates for the protection of those moving about.

Shafts are fitted with Conductors or Guides, which, if of wood or iron, are attached to buntons or crosspieces fixed across the pit and which have either been built into the walling or are afterwards let into it. The strength of the buntons must be proportioned to the size of shaft and the weight of the load; for a shaft 10 feet in diameter with single cages carrying one tram of 12 or 15 cwts., Memel or red pine, 9 inches by 3 inches, placed at intervals of six feet in the shaft, would be sufficient. The guides (if of wood) should also be of Memel pine, not less than 4 inches by 3 inches in section, and properly bolted to the buntons. Bolts and nuts are preferable to wood screws which are often used for this purpose. There is usually only one guide on each side of the cage, but the arrangements respecting them are various, according to the requirements of the case. Frequently, instead of wood, bridge or single headed rails are used for guides, and in some cases angle iron, they being kept in line by suitable fish-plates and bolts, and securely fastened by bolts to the buntons. In Lancashire and Yorkshire some pits have guides consisting of round bars of iron fixed at the pit bottom and screwed up to the head frame. There are two rods for each cage, the cross bar of which, having a ring at each end, runs upon the rods.

In most of the large collieries in South Wales wire-ropes are used as guides,

fixed to wooden balks at the shaft bottom and to the head frame, where they are tightened by screws; another means of keeping them tight is to suspend heavy weights from their lower extremities beneath the balks, or by weights hanging over pulleys on the surface.

Where the depth and consequently the cage-speed is great, three and sometimes four of these guides are required to prevent excessive vibration. In some instances two additional ropes are suspended between the cages to prevent one cage from catching the other in passing. Rigid guides are so fixed that the cages shall have not less than 9 inches of clearance as they pass each other, and if iron wire guides are used and the pit a deep one there should be from 12 inches to 18 inches of clearance, according to the depth of the shaft, the number of guides used, and the speed of the cages in the pit.

"Keeps," "Fans," or "Shuts" are supports for the cage on its arriving at the surface or shaft bottom, and at intermediate loading places, if there be any. They are arrangements of counterbalanced levers, and those placed on the pit top offer no obstacle to the ascent of the cage, which after passing by the "keeps" is lowered by the engine man on to the supports. With double-decked cages, when the tub on the bottom deck has been changed and a signal received that the tub in the top deck (which it must be remembered stands on the shaft bottom "keeps," when the bottom deck of the other cage is on the "keeps" at the surface) is also changed, the engineman lifts the cage from the supports, and the attendant, by means of a lever, pulls them back clear of the cage until the bottom deck is lowered below them, when the attendant lets go his hold of the handle and they form a support to the top deck. During the change here, the tub in the bottom deck is changed at the pit bottom, and this being effected, the cage is lifted by the engine-man, the attendant pulls back the "keeps," the cage is lowered, and when it has descended clear of the "keeps" they are allowed to spring back ready for use again. The "keeps" at the shaft bottom are necessarily handled differently. As the loaded cage leaves the shaft bottom the attendant there pulls the handle of the "keeps" back and secures it there, by this means preventing the "keeps" from protruding in the pit. As the cage in its downward course approaches him, he takes the handle of the lever which works the "keeps" in his hand, and having allowed the bottom deck of the cage to pass below the level of the "keeps" they are allowed to spring out and support the top deck of the cage. The tub is changed here whilst the bottom deck of the other cage is changed at the surface. The "keep" handle will not require further attention from the attendant below until the cage has left for the surface when he secures the handle back in its place.

The Cage is a receptacle for the tubs traversing the pit either empty or full. It is also the usual means of transport for the workmen and all others between the surface and the different loading stages in the shaft. The pit timber, workmen's tools, horse food, and water, and frequently the horses themselves are lowered by means of the cage.

When men are riding in one cage no loaded or empty tubs are placed in the other, or in an under or over deck of that holding them. If men are not in both cages one is allowed to run empty.

The cage is usually made of wrought iron but sometimes of steel. As to its form, it is of course governed by the shape of the division of the shaft it has to run in, and it may be single or double decked or have more decks than two if desirable. Again each deck may have one or more tubs placed in it as may be desired and arranged. Each deck floor is laid with rails to allow of the tubs being pushed in whilst the loaded ones are pulled out on opposite sides. There are various modes of keeping the tub secure in the cage during its ascent or

descent. One of these is by having "false bottoms" in the cage, which is an arrangement whereby the floor of that part of the deck on which the tubs are placed falls or sinks an inch or two below the other and outer portions of the deck, but when the cage rests on the keeps all the deck floor is on one level, allowing the tubs to be changed.

Another mode of securing tubs in the cage is a bar running through the cage and at either end is placed a short lever which turns down or up on being pushed;

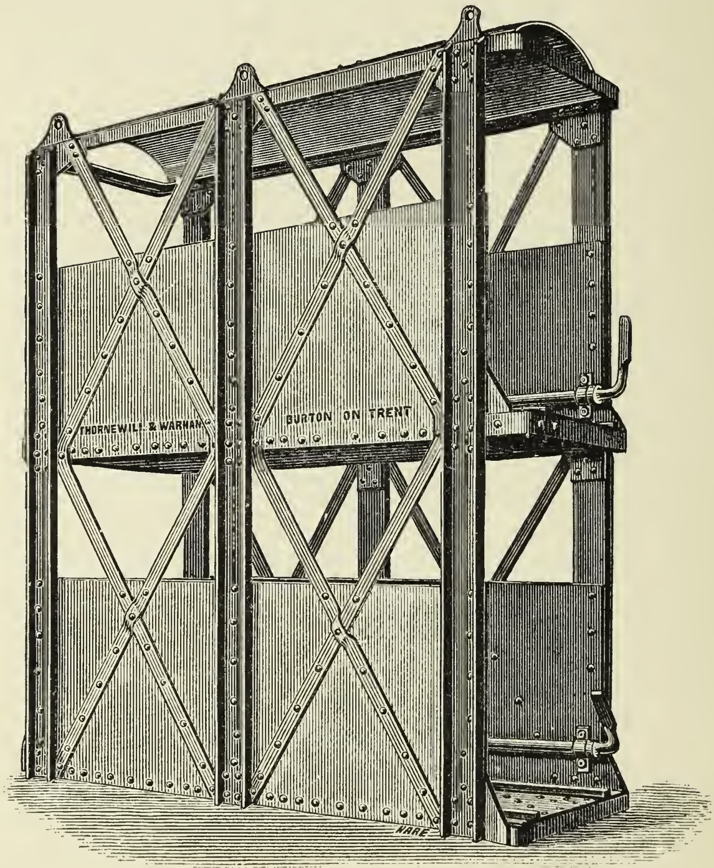


Fig. 38.—Double-decked Cage.

when down it covers the ends of the tubs and prevents their moving, when up it allows them to be changed.

The best form of catch is that which grips the axles on the tub being pushed in, without the necessity for the attendant to have to put his foot on the cage to work the catch. Sometimes a catch in the floor secures the tubs in place.

The slides of the cage fit loosely to three sides of the wooden conductors, and are slightly bell-mouthed. They are applied at the upper and lower bars of the framing.

A two-decked cage would have 3 such slides on either side of it, in the usual arrangement adopted. The top of the cage is provided with an iron bonnet or

cover for the protection of persons whilst descending or ascending. The cage is suspended from the rope by four short chains called "bridle" or "bull" chains, one being at each of the upper corners, and in the case of heavy cages from the middle of the longer sides as well, so that in the latter case there would be six bridle chains.

Fig. 38 shows a double-decked cage, and Fig. 39 a treble-decked cage, as made by Messrs. Thornewill & Warham, Engineers, Burton-on-Trent. The former is steel throughout, the deck frames being angle steel, the uprights of channel steel, and the bracings of flat steel. The deck frames have cross-bearers of angle steel, with "knee" ends riveted to the frames. The floor of each deck consists of perforated steel sheets.

The cage-hangers are of forged steel and sufficiently large to form a gusset to receive the uprights, cross-bracing, and top frame; they have horns forged on them to prevent the D link on bull chains from falling over when the chains are slack.

The treble-decked cage is of similar construction, the uprights being of angle instead of channel steel.

The tub-catches are plain bars with bent ends, working in suitable chocks fixed to the uprights. The roof of each cage is provided with doors, so that long pit wood and other articles may be carried on the upper deck. All rivet holes are drilled and rivets where possible put in by machine. The cages are provided with guide-cheeks for square, or loops for wire rope conductors, and each deck is fitted with rails. The finished weight of the double-decked cage is 2 tons, 3 cwts., 2 qrs., without the bull-chains. They are in daily use at the Walsall Wood Colliery, Cannock Chase, where each cage lifts 8 tubs, holding 48 cwts. of coal per lift from a depth of 550 yards. The treble-decked cage weighs 2 tons, 14 cwts., 2 qrs., without the bull-chains, and is in use at the Hamstead Colliery, near Birmingham, where each cage lifts 6 tubs, holding 84 cwt. of coal per lift from a depth of 620 yards.

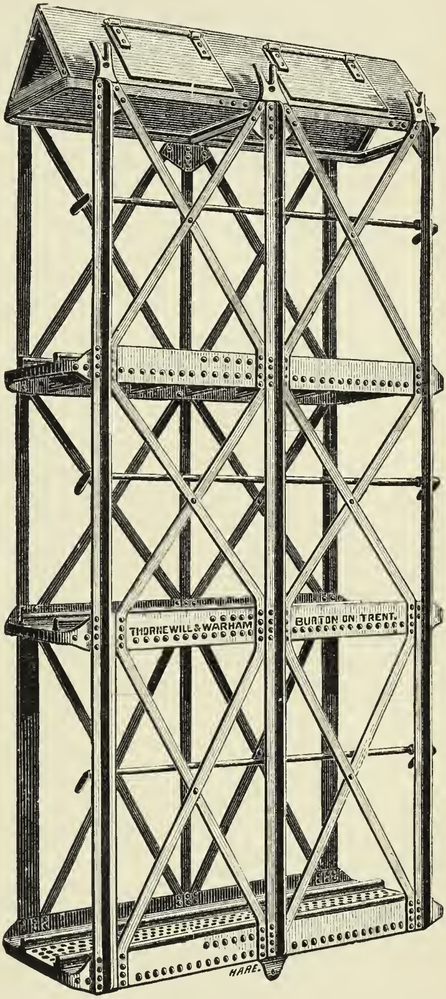


Fig. 39.—Treble-decked Cage.

All cages should be provided with guards to be fixed to, or removed from the top of cages at will, so as to protect workmen who have to stand on the cage roofs or covers during the time they are examining or repairing the shaft, and

where the cover is of a sloping or curved form, a horizontal floor should be attachable over it to enable the workmen to move about and handle their tools.

Sometimes cages have an attachment for arresting their descent in the shaft in the case of a broken rope, and are then called "safety cages." A great number of these safety appliances are before the public, but they do not seem to come into general favour. They all consist of a contrivance for gripping the guides when the strain of suspension is removed.

The uncertainty, however, of their acting when the necessity arises—it may be years after being put in—seems to preclude their adoption as a means of safety.

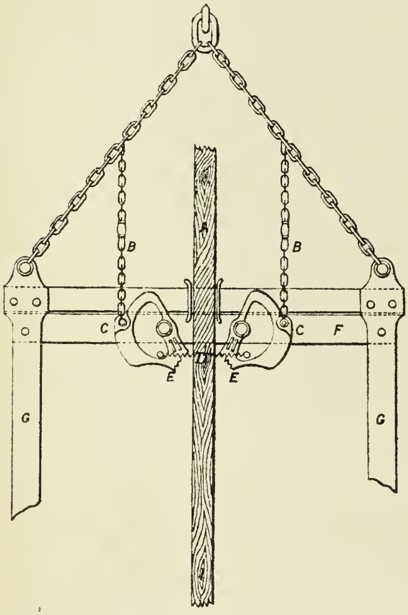


Fig. 40.

Fig. 41.—Broadbent Safety Cage.

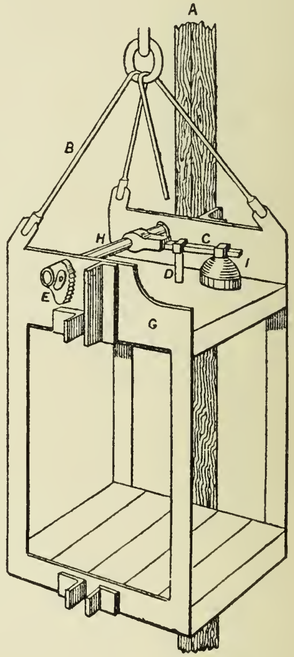


Fig. 42.—Calow's Safety Cage.

Probably the feeling is that, as something must be relied upon, and as the complication and multiplication of appliances, the greater the liability for something to go wrong, it is preferable to rely on good ropes, properly looked after, and worked with a due regard to their margin of safety.

Broadbent Patent Safety Cage.—Fig. 40 shows a side elevation of the apparatus, and Fig. 41 a plan of the eccentrics and guides of Broadbent's patent safety cage. AA are the guides; B the suspending chains; CC levers to which the suspending chains are attached, and which, when the weight is carried, keep the eccentrics EE from coming in contact with the guides; D is a spring for giving motion to the levers CC, and eccentrics EE, if the rope breaks; F a wrought-iron plate at side of cage to carry the apparatus; GG frame-work of cage. From this description it will be readily understood that if the suspending rope breaks, the springs will force the eccentrics EE against the guides, and the cage will remain suspended.

It will also be observed that every time the cage is on the keeps, both at the top and bottom of the pit, the rope will slacken and the apparatus will come into action and press upon the guides. By altering the edges of the eccentrics they can be made to suit iron wire guides.

Calow's Safety Cage.—This differs from Broadbent's inasmuch as it is not dependent on its action on any direct attachment to the rope. Fig. 42 shows a perspective view of the apparatus.

A is a guide, the other being removed for the sake of exhibiting the mechanism of the cage; B the suspending rods or chains; E an eccentric carried by a shaft

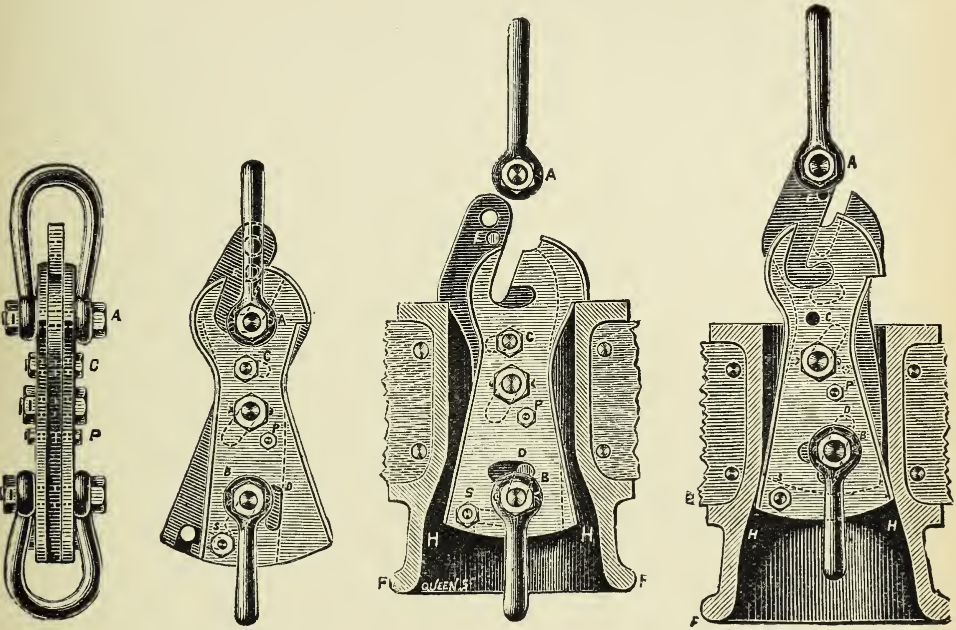


Fig. 43. Fig. 44. Fig. 45. Fig. 46.

ORMEROD'S SAFETY LINK.

H, on which is also keyed a lever, C; D is a spring which is made to suspend the weight I, and keep the eccentrics E clear of the guides so long as the speed of the descending cage does not approach that of a falling body. But by the cage falling, or through any sudden jerk, the pressure of the weight I on the spring D ceases to be so intense, and therefore, the spring lifts it and sets in motion the eccentric E, which grips the falling cage. The apparatus, therefore, does not come into action each time the cage is stopped or rested on the keeps.

There are many other safety cages, but the principle of their operation is somewhat similar to those described.

DETACHING HOOKS.—Closely associated with safety cages are contrivances of a similar character for preventing the cage from falling when severed from the rope through overwinding. The object sought to be accomplished in these overwinding safety appliances is to cause the link by which the cage is suspended from the rope to release its hold of the rope and take hold of a portion of the framework of the headgear.

The Mines Act, 1887, does not make the use of any overwinding appliance compulsory, but a limit of speed is fixed, when men are being raised, if the mine is not provided with an automatic contrivance to prevent overwinding.

Ormerod's is one of the best of these safety links, and is the invention of Mr. Edward Ormerod, of Atherton, near Manchester.

Fig. 43 is a cross view of the link.

Fig. 44 is a side view of the same.

Fig. 45 represents the position it assumes when wound up into the cylinder, the rope shackle being disconnected, and the link firmly locked in its position.

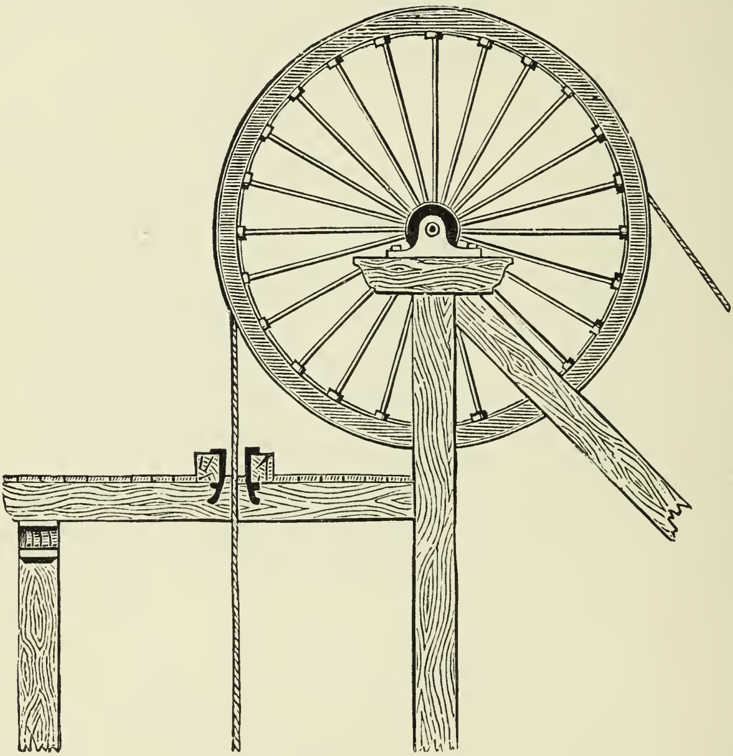


Fig. 47.—Arrangement of Catch-plate in Headgear for Ormerod's Safety Link.

Fig. 46 shows the rope shackle re-connected for lowering the link through the cylinder.

Fig. 47 shows a section of the cylinder as fixed in the headgear or pit frame, also the platform for convenience in re-connecting the rope shackle.

It will be seen on reference to the engravings that the apparatus when in ordinary use, as in Fig. 44, is wider at the bottom than the top; but in the event of overwinding, the link is drawn into the bell-mouthed cylinder F F in Fig. 45, the wide part of the link at H H coming in contact with the cylinder at F F, thereby closing the bottom part of the link, also causing the top part to expand and the projections to catch over the top of the cylinder, while at the same time the rope shackle A is forced out of its seat, thus being allowed to go free; the bottom shackle B drops into the slot D and locks the link firmly in its position. The cage being suspended from the chain cannot fall back. To prevent the possibility of the

link becoming disarranged in ordinary work, a small pin, P, is inserted through the plates, which pin is sheared off as the apparatus passes into the cylinder.

For lowering the cage the shackle is attached to the ear on the middle plate as shown in Fig. 46. On removing the pin C, and slightly winding the rope, the middle plate (having a slotted hole in it) is elevated into the position shown, and allows the apparatus to pass down through the cylinder, and safely lower the cage.

The following advantages are claimed for it :—

1. It is self-contained. The load in ordinary work being carried from the outside plates only, thereby avoiding appreciable wear to its working parts.
2. The clasp stud E, which lips over the top part of the outside plates, considerably strengthens the hook in case of any excessive strain or jerk, and also assists the hook in taking the first shock in case of overwinding at a very high speed.
3. When detached the middle plate constitutes additional metal thrown out, and the hook is therefore actually considerably stronger than when in its working position.
4. The bell-mouthed cylinder for detaching the hook is a substantial and exceedingly strong fixing for the headgear, and is never liable to be torn away, neither does it collapse or injure the ropes through vibration.
5. The cylinder also affords a much more effective entrance for the hook than any other appliance whatever.

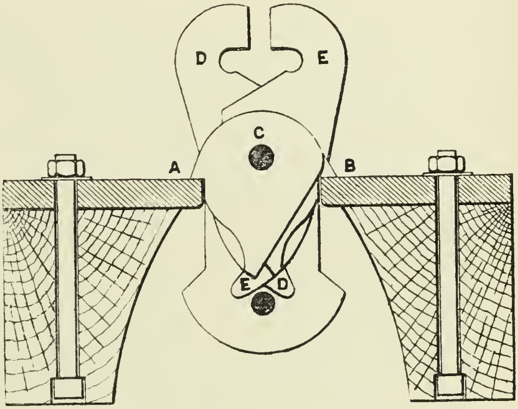


Fig. 48.—Forster and Brindle's Detaching Hook.

Forster & Brindle's is another of these detaching hooks, and is shown at Fig. 48. Two similar plates, A and B, are suspended upon a pin, C, and are made so that in passing through the detaching plate they are pressed in. On emerging from the upper end of the detaching plate they open out again so as to prevent the hook from returning. In case of a partial overwind the hook enters the detaching plate, but perhaps not sufficiently to cause shearing of the rivet which must precede detachment; the plates then clutch the point of sustainment and prevent the cage from falling back. Where the overwind is complete, the plates A and B are pressed in as they pass through the sustaining plate, and immediately after being through, are pressed out by plates D and E, which also cause detachment. The rope is expeditiously re-attached, to effect which the connection with the rope is made, and the weight tightened on it, the two plates, A and B, are pressed in by hand, and kept in whilst being lowered through the detaching plate, after which work may be resumed.

There are many other patent detaching hooks, but the difference between them and those described is not sufficient to justify a description of each.

To some extent the same remarks apply to the use of disconnecting or detaching hooks as those on safety cages. They have been known to fail

at the moment of their need—probably owing to the high speed at which the cage was overwound. A lamentable example of this occurred in Yorkshire in 1886, where the cage with ten men in it was overwound, broke the bolts and fastening of the catch-plate and carried it away. The hook detached at the same time and the cage and catch-plate fell down the shaft and the ten men were killed.

It is necessary sometimes to have pipes placed in the shaft to convey steam or compressed air to an underground engine, and to place pumps or a rope communicating with an underground engine plane from the engine at the surface, but the method of securing the pumps will be described later on.

The HEADGEAR, Fig. 49, consists of a pulley-frame which may be of pitch pine timber, or wrought iron, that in the Fig. being of timber. The uprights,

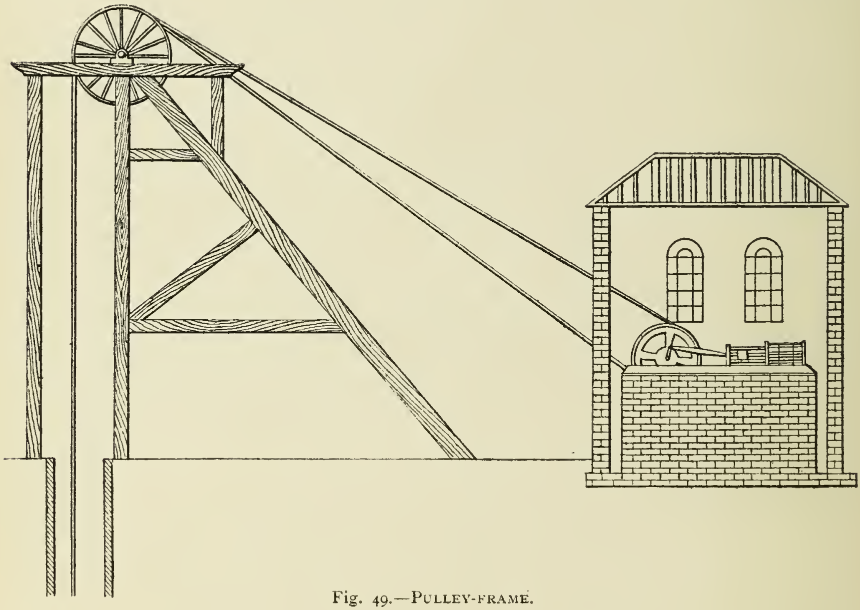


Fig. 49.—PULLEY-FRAME.

two or four in number, forming the frame, and the two back-stays or inclined pieces are the main features of a pulley-frame, and are so arranged as to best resist the strain on the pulleys, which is of a twofold character, viz., the vertical strain from the load in the shaft and a side strain towards the engine. The uprights vary in height from 30 to 70 feet, and are generally made of pitch pine from 12 to 16 inches square. The back-stays are of the same sectional size, and should be placed at an angle to the uprights, and as nearly parallel as possible to the ropes from the drum to the pulleys. A good rule is to let the rope make not less than an angle of 45 degrees in going over the pulley. Diagonals and strengthening pieces are also placed across the uprights near the pulleys for strengthening their support. Pulley-frames made of iron admit of a greater length than wood. It is unwise to have the pulleys placed too near the level of the pit top, for with engines on the first motion, and having large drums, half a stroke of the engine may take the cage to the pulleys.

One of the inclined pieces should have steps and a hand-rail formed on it, or

a separate ladder provided, so as to admit of an attendant going up to examine the head-gear and oil the pulleys.

Each upright should rest in an iron footing placed upon a specially prepared pillar to take the vertical pressure. The backstays should each rest on ashlar

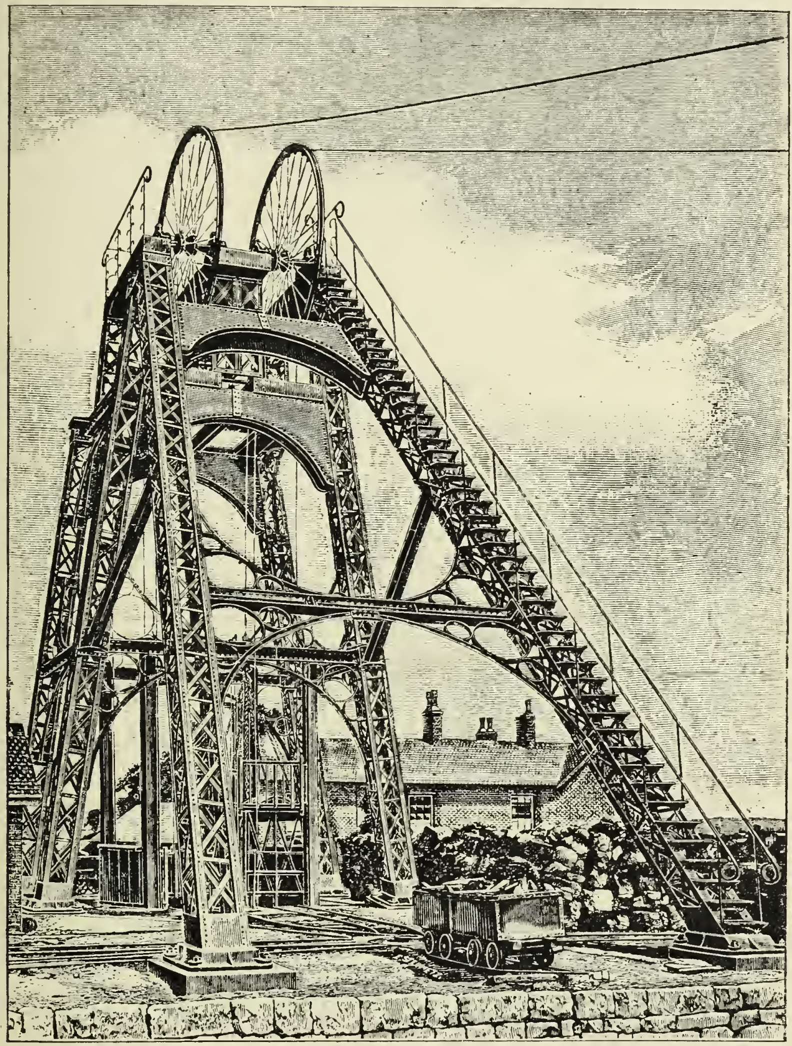


Fig. 50.—Pit-head Frame erected by Messrs. Thornewill & Warham at the New Hall Park Collieries.

or concrete foundation, and not against the engine house wall. Where space is limited and the engine house is necessarily erected rather near the shaft, there is no objection to the backstays being taken through the engine house wall so as to rest against the engine pillars. They should always be taken up to the centre of the pulleys, and not as sometimes seen to a point below this which gives the backstays less resisting power to the strain on them. The whole framework should be frequently painted for the preservation of the material composing it.

The pulleys, usually placed side by side, have wrought iron arms, the rim and central boss being generally of cast iron. They should be placed with proper regard to the lead of the ropes off the drum to the pulleys, so that the angle of the rope to each is equal. The rim is made to suit the kind of rope to be used, and is grooved accordingly. Pulleys are usually from 10 to 20 feet in diameter. In deciding on a suitable size, it must be borne in mind that ropes receive more injury from working over small pulleys than over large ones, and consequently wear out quicker. A good plan is to have the pulleys the same size as the drum of the winding engine, a rule for ascertaining which is given later in this Chapter. Provision must always be made for their adjustment and oiling.

Fig. 50 shows a Pit-head frame which is elegant in appearance and of great strength, as made by Messrs. Thornewill & Warham, Engineers, of Burton-on-Trent, and erected at the Earl of Carnarvon's New Hall Park Collieries, near Burton-on-Trent. The general arrangement of the pit bank is also shown in the Figure.

The height from pulley centres to pit bank is 40 feet, the pulleys being 15 feet in diameter. The legs are of open lattice work with $4'' \times 4'' \times \frac{1}{2}''$ angle iron bars connected by flat bars $2\frac{1}{2}'' \times \frac{1}{2}''$, and are suitably cross-braced and stiffened by plate girders and spandrils of various sections.

The platform around the pulleys is fenced and access thereto is obtained by a stairway on one of the back-legs.

The pulleys are of the usual type, having cast-iron rims and bosses with wrought-iron arms, and are fitted with steel spindles having journals running in pedestals with adjusting screws and ample lubricating boxes attached.

The legs are provided with cast-iron plates at their feet, bedding on stone blocks mounted on brick pillars, and secured by large foundation bolts.

For lighter loads and small plants the frames are constructed of I and ⊔ iron sections and are very neat, and strong, and preferable to wood.

When required for shipment the frames are erected, and marked before being taken to pieces, and the necessary bolts provided for locking together in re-erection.

Ropes are now usually made of steel wire of different qualities, all being stronger than iron for the same size; and they may be round or flat. The round are preferable and certainly the most popular. Ropes of hemp are also used, but only to a limited extent, and are gradually falling into disuse for winding.

Wire ropes should be carefully protected with best water-proof grease. The safe working load of ropes may be taken at from $\frac{1}{5}$th to $\frac{1}{8}$th of the breaking strain. A close approximation to the safe working load of ordinarily-made wire ropes moving at high speeds is found by multiplying the weight of the rope per fathom in pounds by 5 for iron wire, and by 8 for steel wire, and consider the product as hundred-weights. Thus, an iron wire rope, weighing 16 lbs. a fathom, has a safe working load of $16 \times 5 = 80$ cwt.; a steel wire rope of the same weight, $16 \times 8 = 128$ cwt. These are only rough approximations—rules that can be easily carried in the memory. André, in his *Treatise on Coal Mining*, gives the following rules to find the safe working load. $C = \sqrt{4\ L}$ for iron wire and $C = \sqrt{2{\cdot}4\ L}$ for steel wire, where $C =$ the circumference of the rope in inches and $L =$ the safe working load, and therefore $L = \frac{C^2}{4}$ for iron wire and $\frac{C^2}{2{\cdot}4}$ for steel wire.

The following rules were at one time used by some rope manufacturers, but the difference in quality of the materials used renders the rule of little practical value. Owing to this difference probably, there is a want of uniformity in the strength of similarly-sized ropes quoted by manufacturers. Let $B =$ breaking weight in tons, and $W =$ weight per fathom in pounds. Then for hemp ropes $W = B$; for iron wire ropes $W = {\cdot}55\ B$; and for steel wire ropes $W = {\cdot}33\ B$. Or,

where C = circumference of rope in inches (where the ropes are flat C will answer for the perimeter) and B = breaking weight in tons.

Then for hemp ropes $B = \cdot 25\ C^2$; for iron wire ropes $B = 1\cdot 5\ C^2$; and for steel wire ropes $B = 2\cdot 5\ C^2$.

The working or safe load is for—

	Round	Flat	
Hemp ropes . . .	$\frac{1}{7}$th	$\frac{1}{8}$th	of breaking strain.
Iron wire	$\frac{1}{7}$th	$\frac{1}{8}$th	do.
Steel wire . . .	$\frac{1}{6}$th	$\frac{1}{7}$th	do.

Suppose, then, it becomes necessary to know the diameter of wire rope which would be equal in strength to a hemp one of 4 inches diameter, it would be found thus: the ratio that the square of the diameter of an iron wire rope bears to a hemp one in point of strength is as $1\cdot 5 : \cdot 25$. Therefore as $1\cdot 5 : \cdot 25 :: 4^2 : 2\cdot\dot{6}$, and $\sqrt{2\cdot\dot{6}} = 1\cdot 633$ inch as the diameter of the iron wire rope. Similarly, if it be required to know the diameter of steel wire rope which would be equal in strength to the hemp one of 4 inches in diameter and the iron wire rope of 1·633 inch in diameter, the reasoning would be thus: the ratio that the square of the diameter of the steel wire rope bears to the hemp one in point of strength is as $2\cdot 5 : \cdot 25 :: 4^2 : 1\cdot 6$ and $\sqrt{1\cdot 6} = 1\cdot 265$ inch as the diameter of the steel wire rope.

The duration of a rope depends upon circumstances. If placed in a wet shaft where the water is impregnated with mineral acids, or in an upcast shaft where gases injure the ropes, they will not last so long as those working in dry shafts. Ropes subjected to rapid winding are injured more than where slow speeds of winding prevail. The average duration of flat wire ropes is usually taken at one year, and that of round ropes at a year and a half; but it is impossible to fix a hard and fast line, on account of the great difference in circumstances under which ropes work. The speed of winding, freedom from chemical action, careful attention and greasing, the number of hours used per day and the number of days per year, are all elements affecting the duration. In putting on a rope care should be taken to pass it through the exterior of the drum on an easy curve, and then to coil it round the drum-shaft once or twice before securing it thereto. A rope should be long enough to admit of a couple of coils on the drum when the cage is lowered to the pit-bottom. The other end of the rope is secured to the cage by "capping."

The most frequently used method of "capping" a round wire rope is as follows:—A strip of iron is worked into suitable shape to form the cap. The central portion is well rounded for a few inches, sufficient when the two ends are afterwards bent over towards each other to form a strong loop or bow to take the D link which holds the cage bridle-chains. The two sides of the cap are rather smaller at the ends than next the loop, and are curved to receive the rope between them. Rivet-holes are drilled opposite each other in the two sides. Besides this socket, two rings of iron are prepared of such sizes as to afterwards fit tightly over the joint. These rings are closed before going on, and fit somewhat loosely over the rope; they are passed over the end whilst hot. About 2 feet back from its end a piece of copper wire is now bound round the circumference of the rope. The wires at the extremity are then opened and folded back upon the rope, the fold taking place at the copper-wire binding. Another length of copper wire is carefully and tightly wound over the folded wires so as to bring them into close contact with the rope and prevent any wires from projecting. As the binding proceeds upwards the folded wires are thinned gradually by cutting off a few at a time, until, when the binding has reached the top, a cone has been thereby formed at the extremity of the rope. In this state the rope is inserted between the two sides of the socket, which are easily spread open for the purpose. The sides are then, by means of clamps, pressed tightly against the rope and held firmly so, whilst rivets are driven through the socket and the heads formed on

the rivets. The operation of riveting is attended with some practical difficulty. The holes are not drilled recklessly through the rope, as a drill in advancing straight across would sever many of the wires obliquely crossing its course, and so weaken the rope. To avoid cutting the wires and yet obtain a passage through them and past the cores without injury, a short needle is used, having a point at one end and a head and eye at the other. The needle is struck by a hammer or turned by passing a short rod through the eye, whilst attempts are made to direct it to form an opening between the wires and past the cores, without cutting them, in line to the corresponding rivet-hole on the opposite side. Frequently the needle, after piercing the rope, reaches the other side considerably off the desired point, and many fruitless attempts are made before the object sought is accomplished. When the rivets, usually three in number, are closed, the larger of the two rings, which was put over the rope last, is brought down over the joint and firmly pressed into its position on the socket near its bottom end. The other ring is then served similarly. It takes up a position near the top of the joint. As the rings cool they contract and tightly grip the socket.

Fig. 51 shows the capping on a rope performed in this way. The object of the rings is to prevent the socket from opening or parting from the rope. They give additional security to the rivets by resisting the force within the joint (resulting from lifting and raising the cages); and after the rope has been running some time, if the rivets give way, the rings still have considerable grip on the rope, because the bottom end of the socket is larger in diameter than the top (due to the folded and cut wires), and the strain caused by lifting the cages tends to pull the rope through, and so wedge into closer contact the rope, socket and rings.

At some collieries the practice is to put the rings on in a cold condition. Where put on hot, it often happens that the time taken to bind the copper wire and drive the needles has allowed the rings to cool. They may, however, be heated again whilst on the rope before being dropped into place on the socket.

Another method of capping a round wire rope is shown at Fig. 52. A piece of round iron sufficiently long to form the socket and of slightly tapered form, has a conical opening bored through it. Near its lower extremity, which has also the larger diameter, a bolt-hole is cut, the two circular openings being opposite each other. The rope is threaded through the aperture from its upper end, the opening being just large enough to allow of this. The lower extremity is slightly larger. The wires of the rope are folded back when the rope is well through the socket, and the end, as now shaped, pulled back into the aperture. The two bindings of copper wire should be wound as in the previously described method.

The folded wires prevent the rope from being pulled farther than a point sufficiently clear of the bolt-hole. Molten lead is now poured from a ladle in through the larger diameter of the aperture, the socket being inverted for the purpose. The lead fills up all the interstices between the rope and the inner sides of the socket. It is then allowed to cool, when the lead and rope form a hard solid mass within the aperture strong enough without rivets to resist the strains put upon it afterwards. A D shaped link for the reception of the cage chains is secured by a square-headed bolt passed through the bolt-hole in the socket and kept firmly in place by a cottar, driven down vertically at the tail end of the bolt. Besides the molten lead, a plug with a thread formed on it is screwed into the socket on the under side.

A third method of capping a round pit-wire rope consists in preparing a wrought-iron socket with the loop formed at its lower extremity and welding the socket down one side, leaving the central conical opening as in the other methods. Rivet-holes are then drilled in the socket, and the manner of further procedure is much the same as in the first described method. The first given method of capping is preferable, as it allows of the rope within the socket to be partially

examined, whereas in the other methods the rope at the cap is quite hidden from view.

At some collieries it is customary to fix the cappings without the use of rivets. Where this practice is followed, three or four rings or hoops are used, according to the size of the rope, the weight to be lifted, and the length of the cap. After slipping the hoops up the rope in their proper order according to size, the rope may be prepared in one or two ways. Small wire is tightly bound round the rope

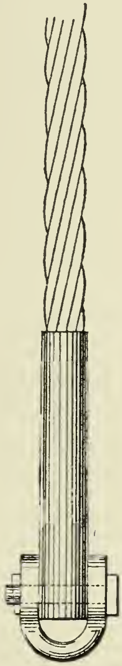


Fig. 52.

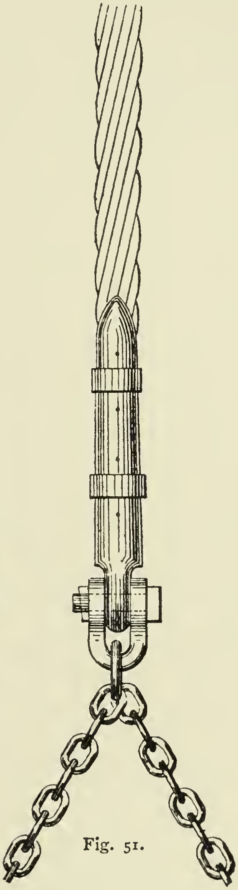


Fig. 51.

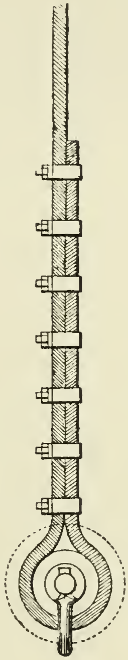


Fig. 53.

Wire-rope Capping.

two feet from the end, the strands are untwisted and the core of the rope removed. The wires are then bent back the opposite way to the strand, care being taken to tuck them under every other strand, and also to cut off some wires between each tuck so as to make the rope taper for receiving the cap; or it may be done after cutting away the core by bending back the whole of the wires around the rope, thinning them out to the required taper. In each case after the tucking or turning back is completed, small wire is wound round outside so as to make the rope as solid and uniformly taper as possible. The cap, having been made hot at the bow, is then laid to the rope and by means of clamps pressed down tightly to it; the hoops are then slipped down over the cap and driven home.

Caps should be made of the best selected iron, and those for round ropes be made upon a tapered mandrel, so that they may be well shaped.

In frosty weather, the first cage journey should not be started with a full load —it is much better to give the ropes one or two runs with light loads before starting full work.

The systems of capping round pit wire-ropes are adopted also on incline and engine plane ropes, except that in their cappings the rings, or hoops, which would be inconvenient, are omitted.

With flat wire ropes, the method of capping differs from any just described. Fig. 53 illustrates the plan adopted. A portion of the end of the rope is doubled back over a wooden roller (protected by a thin covering of iron) through the centre of which is a bolt-hole. Above the roller, the surface of the doubled back portion of the rope is pressed firmly against the surface of one side of the rope. It is secured in this position by a series of glands placed about a foot apart. The gland consists of a three-sided strip of flat iron except at the extremities where it is rounded, and a thread cut to take a nut. Another flat plate, which is a straight plate rather longer than the width of the rope, is passed over the ends of the three-sided plate whilst the latter is in position, accurately fitting round the joined portion of rope. A nut is then run on the thread prepared at either side of the gland, and the doubled rope is tightly gripped within the two plates, as it is enclosed by their four sides.

Two discs or cheeks of thin iron, having boltholes cut to correspond with that in the roller, are bolted one at either side of the roller, each bolt going through the two discs and the roller. The diameter of the discs is sufficient to form flanges to the roller and keep the rope securely on it. A D shaped link is then fastened by means of a bolt to the underside of the roller and this link receives the cage chains.

In some instances, a short iron cylindrical tube is used without the interior packing of wood, round which the rope is passed, and the D link secured below by a bolt passed through the interior of the tube. No flanges are used, the D link at the bottom of the rope preventing its slipping from the iron roller, which is slightly longer than the width of the rope. This is a very simple method of capping, but not quite so safe as some others.

Another method of capping flat wire ropes is by using a wooden block of a pear-shaped instead of a circular section. The thin end is placed upwards, and it is bored with a central hole. Where the rope passes round this wooden block long or short clamps are used. The clamps are shaped to suit the blocks, and are provided with bolt-holes to receive bolts and nuts above and below the wooden block for securing the rope. With a long pair of clamps, there may be one bolt below and three or four pairs above. With a short pair of clamps, one bolt is placed below and a pair above the block. Above the short clamps two or three separate pairs of short plates, rather longer than the width of the rope, are placed, each pair being provided with bolt-holes through which, by means of two bolts and nuts, they are brought to bear upon the rope between them. Before being tightened, oval-shaped pieces of wood are inserted between the two surfaces of the doubled rope at points intermediate to the pairs of plates. These bulge the rope out and form it into wedge-shaped portions which tend to keep the rope tight against the plates and so prevent it from slipping.

At some collieries, a practice, which is to be recommended, is to re-cap the ropes periodically, say every 3 months or so, whether there is any apparent necessity or not.

When fixing a new rope it should be carefully uncoiled off a reel used for the purpose.

The following observations for users of wire-ropes by Messrs. Wilkins & Co.,

the well-known wire rope manufacturers, are much to the point and deserve the attention of all interested :—

" *Qualities of Steel Wire.*—There are four qualities of Steel Wire used for Wire-Rope making, viz. :

	Breaking Strain.		Per square inch Sectional area
Extra Plough Steel	110 to 120	Tons	
Mild Plough Steel	95 to 100	,,	do.
Best Patent Steel	80 to 85	,,	do.
Bessemer Steel	40 to 45	,,	do.

"*Plough Quality Steel Wire.*—Ropes made of good Patent Steel Wire of a tensile resistance equivalent to 80 to 85 tons per square inch, usually prove more satisfactory than those made of Plough quality Steel Wire, which is always very speculative, especially when run at high speed and round pulleys except those of very ample diameter.

" *Specifications.*—Users of Wire Ropes would often buy more advantageously by first submitting specification of working to the Wire Ropemaker for advice as to the kind of rope best adapted to any particular work. Specifications should state: 1. Length of Rope. 2. Size of Gear. 3. Speed. 4. Load, exclusive of Rope. 5. If for wet workings. 6. Rate of incline. 7. Particulars of curves.

" *Working Loads.*—Many Ropes are seriously damaged by being overloaded. The maximum working load at average speed, including weight of Rope, should not exceed an eighth of the breaking strain, or at high speed a tenth of the breaking strain.

" *Gear.*—Great care should be taken that Wire Ropes are not worked round drums or over pulleys (at brows or angles of whatever degree) of insufficient circumference, and that they do not strike against any hard substance while in motion.

" *Storing.*—Wire Ropes must be very carefully stored. They should on no account be placed on the ground, but on sound planks raised several inches from the earth, so that they may be free from damp. They should also be covered with a tarpaulin and regularly inspected from time to time.

" *Uncoiling.*—Much care should be taken in uncoiling Wire Ropes, to prevent kinking. The coil should not be laid stationary, but should be placed on a turntable or reel. Unwind from the outer end.

" *Grease.*—To prevent corrosion, all working Ropes should receive a regular dressing thoroughly laid on by passing the rope between roller brushes well fed with Wire Rope Grease.

" *Starting.*—The greatest strain on a Rope being at the moment of starting, every care should be taken to insure perfect steadiness of movement, as jerking is ruinous to Ropes.

" *Changing Ropes.*—A Rope may be changed from a smaller to a larger drum, but not from a larger to a smaller one.

" *Lightning Conductors.*—Undoubted evidence exists of the explosion of firedamp in Collieries through sparks from atmospheric electricity being led into the Mine by the Wire Ropes of the shaft and the iron rails of the galleries. Hence the headgear of all shafts should be protected by proper Lightning Conductors as suggested in the Report of the Lightning Rod Conference, 1881.

" *Safety.*—Nothing costs too much on which life depends."

The following tables of breaking strains and working loads of ropes, and also the weights and strengths of chains, are issued by Mr. Frederick W. Scott, another well-known rope manufacturer :—

Comparative Table of the different qualities of Steel Wire Round Ropes, showing Breaking Strains and Working Loads.

Approx. Weights per Fathom.		Bessemer Steel or Substitute for Charcoal Iron.	Crucible Cast Steel.	Improved Patent Steel.	Improved Plough Steel.	Breaking Strain. Tons.	Working Load. Cwts.
Size. Cirfe.	Lbs. p. Fm.						
3/4	3/4	1 1/8	1	7/8	3/4	2	4 1/4
7/8	1	1 3/8	1 1/4	1 1/16	7/8	3	6 3/4
1	1 1/4	1 5/8	1 1/2	1 1/4	1	4	8 3/4
1 1/8	1 1/2	1 3/4	1 5/8	1 3/8	1 1/8	5	11
1 1/4	1 3/4	2	1 3/4	1 1/2	1 1/4	6	13 1/4
1 3/8	2	2 1/4	2	1 5/8	1 3/8	7 1/2	16 1/2
1 1/2	2 1/2	2 3/8	2 1/8	1 3/4	1 1/2	9	20
1 5/8	3	2 1/2	2 1/4	2	1 5/8	10 1/2	23 1/4
1 3/4	3 1/4	2 3/4	2 1/2	2 1/8	1 3/4	13	29
1 7/8	3 3/4	3	2 5/8	2 1/4	1 7/8	14 1/2	32 1/4
2	4 1/4	3 1/8	2 3/4	2 3/8	2	17	37 1/2
2 1/8	4 3/4	3 3/8	3	2 1/2	2 1/8	18	40
2 1/4	5 1/4	3 1/2	3 1/8	2 5/8	2 1/4	21	46 1/2
2 3/8	6	3 3/4	3 1/4	2 3/4	2 3/8	22	49
2 1/2	6 1/2	4	3 1/2	3	2 1/2	25 1/2	56 3/4
2 5/8	7	4 1/4	3 3/4	3 1/4	2 5/8	28	62 3/4
2 3/4	8	4 3/8	3 7/8	3 3/8	2 3/4	31	69
2 7/8	8 1/2	4 3/4	4	3 5/8	3	36	80
3	9	4 7/8	4 1/8	3 3/4	3 1/8	39	86
3 1/8	9 1/2	5	4 3/8	3 7/8	3 1/4	42	93
3 1/4	10 1/4	5 1/2	4 5/8	4	3 1/2	49	109
3 3/8	10 3/4	5 3/4	5	4 1/2	3 3/4	56	125
3 1/2	12	6	5 1/2	4 3/4	4	67	149
3 5/8	12 3/4	6 1/2	6	5	4 1/4	76	169
3 3/4	13 1/2	7	6 1/4	5 1/2	4 1/2	88	196
4	15 3/4	7 1/4	6 5/8	5 3/4	4 3/4	94	209
4 1/8	16 1/4						
4 1/4	17 1/2						
4 3/8	18 3/4						
4 1/2	20						
4 5/8	20 3/4						
4 3/4	21 1/2						
4 7/8	22						
5	22 3/4						
5 1/4	24						
5 1/2	26						
5 3/4	30						
6	34						
6 1/4	37						
6 1/2	40						
6 5/8	43						
7	48						
7 1/4	52						

The Weights of Ropes given are for Wire Cores in Strands and Main Core of Hemp.

From $3\frac{1}{2}''$ to $7\frac{1}{4}''$ the weights are for Ropes made compound.

The weights of Compound Ropes vary according to construction.

For Hemp Cores in the Strands deduct $\frac{1}{8}$th for sizes down to $3\frac{3}{8}''$.

For Wire Main Core add $\frac{1}{6}$th to the weights given above.

Comparative Table of the different qualities of Steel Wire Flat Ropes, showing Breaking Strain and Working Loads.

Approximate Weight per Fathom.		Bessemer Steel, or Substitute for Charcoal Iron.	Crucible Cast Steel.	Improved Patent Steel.	Improved Plough Steel.	Breaking Strain.	Working Load.
Size.	Lbs. p. Fm.					Tons.	Cwts.
$2\frac{1}{2} \times \frac{1}{2}$	13	$2\frac{1}{2} \times \frac{1}{2}$	...	...	...	$19\frac{1}{2}$	43
$2\frac{5}{8} \times \frac{1}{2}$	14	$2\frac{3}{4} \times \frac{1}{2}$	...	...	...	23	51
$2\frac{3}{4} \times \frac{1}{2}$	15	$3 \times \frac{5}{8}$	...	...	...	25	55
$3 \times \frac{5}{8}$	19	$3\frac{1}{4} \times \frac{5}{8}$	$2\frac{1}{2} \times \frac{1}{2}$	...	...	28	62
$3\frac{1}{8} \times \frac{5}{8}$	21	$3\frac{1}{2} \times \frac{11}{16}$	$2\frac{3}{4} \times \frac{1}{2}$	$2\frac{1}{4} \times \frac{3}{8}$	...	32	71
$3\frac{1}{4} \times \frac{5}{8}$	22	$3\frac{3}{4} \times \frac{3}{4}$	$3\frac{1}{4} \times \frac{5}{8}$	$2\frac{3}{4} \times \frac{1}{2}$	$2\frac{1}{4} \times \frac{3}{8}$	36	80
$3\frac{1}{2} \times \frac{11}{16}$	23	$4 \times \frac{3}{4}$	$3\frac{1}{2} \times \frac{11}{16}$	$3 \times \frac{5}{8}$	$2\frac{1}{2} \times \frac{1}{2}$	44	$97\frac{3}{4}$
$3\frac{3}{4} \times \frac{3}{4}$	27	$4\frac{1}{4} \times \frac{13}{16}$	$3\frac{3}{4} \times \frac{3}{4}$	$3\frac{1}{8} \times \frac{5}{8}$	$2\frac{5}{8} \times \frac{1}{2}$	49	109
$4 \times \frac{3}{4}$	30	$4\frac{1}{2} \times \frac{7}{8}$	$4 \times \frac{3}{4}$	$3\frac{1}{4} \times \frac{5}{8}$	$2\frac{3}{4} \times \frac{1}{2}$	55	122
$4\frac{1}{4} \times \frac{13}{16}$	32	$4\frac{3}{4} \times \frac{7}{8}$	$4\frac{3}{8} \times \frac{13}{16}$	$3\frac{1}{2} \times \frac{11}{16}$	$3 \times \frac{3}{8}$	68	151
$4\frac{3}{8} \times \frac{13}{16}$	33	$5\frac{3}{4} \times 1$	$4\frac{7}{8} \times \frac{7}{8}$	$3\frac{3}{4} \times \frac{3}{4}$	$3\frac{1}{4} \times \frac{5}{8}$	79	$175\frac{1}{2}$
$4\frac{1}{2} \times \frac{7}{8}$	31	$6 \times \frac{3}{4}$	$5 \times \frac{15}{16}$	$4 \times \frac{3}{4}$	$3\frac{1}{2} \times \frac{11}{16}$	91	202
$4\frac{3}{4} \times \frac{7}{8}$	32	...	$5\frac{3}{4} \times 1$	$4\frac{1}{2} \times \frac{7}{8}$	$3\frac{3}{4} \times \frac{3}{4}$	105	233
$4\frac{7}{8} \times \frac{7}{8}$	34	...	...	$4\frac{3}{4} \times \frac{7}{8}$	$4 \times \frac{3}{4}$	110	244
$5 \times \frac{15}{16}$	37	...	...	$5\frac{1}{4} \times \frac{15}{16}$	$4\frac{1}{4} \times \frac{13}{16}$	125	277
$5\frac{1}{4} \times \frac{15}{16}$	38	...	...	$5\frac{3}{4} \times 1$	$4\frac{1}{2} \times \frac{7}{8}$	148	329
$5\frac{3}{4} \times 1$	41						
$6 \times \frac{3}{4}$	44						

The Weights of Ropes given are for Wire in centre of each Strand, if made Hemp centres, deduct about $\frac{1}{9}$th.

Conductors or Guide Rods.

Circumference	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{4}$ inches.
Weight per Fathom	$8\frac{1}{4}$	9	$10\frac{1}{2}$	$11\frac{1}{2}$	$13\frac{1}{2}$	$15\frac{7}{8}$	$18\frac{1}{2}$	$31\frac{1}{2}$	25 lbs.

Table of Weights and Strengths of Chains.

Diameter. Inches.	Weight per Fathom. Lbs.	Proof Strength. Tons.	Diameter. Inches.	Weight per Fathom. Lbs.	Proof Strength. Tons.
$0\frac{5}{16}$	$5\frac{1}{2}$	1·27	$1\frac{3}{16}$	76	29
$0\frac{3}{8}$	8	1·83	$1\frac{1}{4}$	84	32
$0\frac{7}{16}$	$10\frac{1}{2}$	2·5	$1\frac{5}{16}$	93	35
$0\frac{1}{2}$	$13\frac{3}{4}$	4	$1\frac{3}{8}$	102	38
$0\frac{9}{16}$	17	5	$1\frac{7}{16}$	111	41
$0\frac{5}{8}$	22	6	$1\frac{1}{2}$	120	44
$0\frac{11}{16}$	26	7·25	$1\frac{9}{16}$	128	48
$0\frac{3}{4}$	30	10	$1\frac{5}{8}$	136	52
$0\frac{13}{16}$	36	11·5	$1\frac{11}{16}$	142	56
$0\frac{7}{8}$	42	13	$1\frac{3}{4}$	148	60
$0\frac{15}{16}$	49	15	$1\frac{13}{16}$	150	65
1	55	18	$1\frac{7}{8}$	162	70
$1\frac{1}{16}$	60	22	$1\frac{15}{16}$	171	75
$1\frac{1}{8}$	68	26	2	180	80

Self-acting incline ropes, and hauling ropes frequently require splicing as a result of breakage. Pit ropes, are, for obvious reasons not spliced.

A common method of repairing a broken rope is by a shackle joint. The method of capping a rope, shown in Fig. 51, is to a large extent followed, but the rings over the joint would be greatly in the way and are therefore not used. A socket with bow having been riveted to one end of the broken rope, the other

Fig. 54.—Repairing Broken Wire-rope.

end is similarly treated and the two ends are joined by means of a link passed through the two loops and carefully closed, see Fig. 54. A rope joined in this way may last a long time, but there is an increased amount of friction caused by the joint passing over the rollers.

The following method of splicing ropes is advised by Mr. Frederick W. Scott, of Reddish, near Stockport :—

"In splicing a wire rope the greatest care should be taken to leave no projecting ends or thick parts in the rope. Heave the two ends taut, with block and

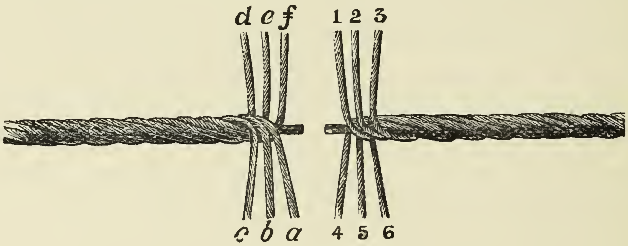


Fig. 55.—Rope-splicing.

fall, until they overlap each other about twenty feet. Then open the strands of both ends of the rope for a distance of ten feet each; cut off closely the main heart or cores (see Fig. 55), and then bring the open bunches of strands face to face, so that the opposite strands interlock regularly with each other.

"Secondly.—Unlay any strand, *a*, and follow up with the strand 1 of the other end, laying it tightly into the open groove left upon unwinding *a*, and making

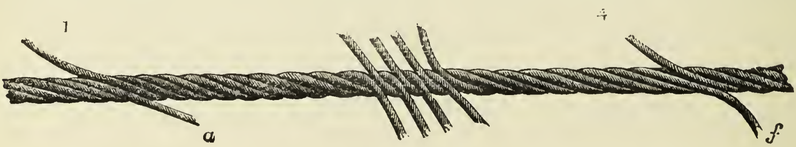


Fig. 56. Rope-splicing. Fig. 57.

the twist of the strand agree exactly with the lay of the open groove, until all but about six inches of 1 are laid in, and *a* has become twenty feet long. Next cut off *a* within six inches of the rope (see Fig. 56), leaving two short ends, which should be tied temporarily.

"Thirdly.—Unlay a strand, 4, of the opposite end, and follow up with the strand *f*, laying it into the open groove, as before, and treating it precisely as in the first case (see Fig. 57). Next pursue the same course with *b* and 2, stopping, however, within four feet of the first set; next with *e* and 5; also with *c*, 3, and *d*, 4. We now have the strands laid into each other's places, with the respective ends passing each other at points four feet apart, as shown in Fig. 58.

"Fourthly.—These ends must now be secured and disposed of, without increasing the diameter of the rope, in the following manner:—Insert marlinespike through the centre of rope and cut out six inches of main core, and place the end of 1 under *a* into the place occupied by the core, and then cut out the core in the same way on the right and place the end of *a* into the place of the core in like manner.

"The ends of the strands should be straightened and lapped with fine hemp seizing before being put in. Then dispose of the remaining ends alternately in the same manner. After having done this, the rope should be well closed, and any unevenness or irregularity can be taken out by pounding it with a wooden mallet.

"In cases where ropes are heavily worked, when tucking in the ends pass No. 1 over *a* and *b* over No. 1. This mode of splicing ensures a very tight grip, and has been found to answer admirably."

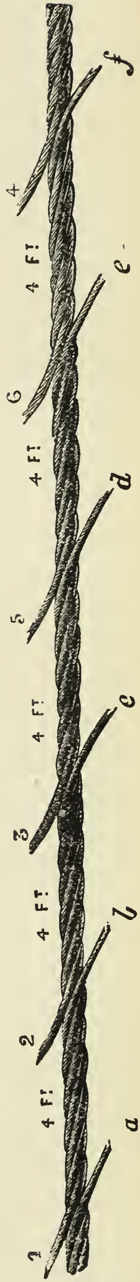


Fig. 58.—Rope-splicing.

This method of splicing is most effective, but as it occupies a considerable time to perform it is not usual to splice the rope during the working hours of the day. To do so then would interfere with the pit traffic, more especially in the case of a hauling rope, and seriously reduce the day's landings and workmen's earnings. At well-conducted collieries, spare shackles are kept ready for use at a moment's notice. If a rope break, the rope repairer, provided with the shackles, joins the broken ends in accordance with Fig. 54, and the pit is soon in full operation again. But this is regarded only as a temporary expedient for getting the day's coal out with the least possible reduction in output. When operations for the day cease, and at a time when the temporarily joined rope is not in use, the rope splicer descends the shaft, takes off the shackles and carefully performs the splice shown in Figs. 55—58.

Shaft Signals.—Separate and distinct signals are required between the pit top and every stopping or landing place in the pit and *vice versâ*. The system may be either the ordinary one of wires working bells or hammers, or by electric signals, speaking tubes, or telephones. Whatever system is employed a code of signals is necessary.

In deciding on a system of signalling the importance of some means of communication between the men in the cage while being drawn up or let down the shaft, should be kept in view. Electricity offers the best means of attaining this object in dry shafts, as each cage may work through a wire, or a couple of wires placed close together, within easy reach of those in the cage. Besides the facility thus offered for the occupants of the cage to signal to the surface in case of accident, electric signals would be convenient to those engaged in the examination or repairing of the shaft.

An electrical shaft signal has been invented and patented by Mr. W. Armstrong, jun. It is an electrical appliance by which signals can be interchanged between those in a cage either in motion or at rest and the engineman. An insulated core is carried in one of the strands of the winding rope, the lower end being attached to a ringing key in the cage, and the upper to a commutator on the engine shaft, through which the

current passes to an ordinary stroke bell. Telephones are used and conversation carried on between the occupants of the cage and the engineman at any portion of the winding.

THE STAGE AND ITS FITTINGS.—The stage should be arranged to suit the particular circumstances of the colliery, but a good plan is to raise it on cast iron columns 20 to 24 feet above the railway level to allow for proper screening arrangements and for the largest trucks to be loaded under the screens.

Besides screens the staging should carry the weighing machine, tables and cabins. There may also be a small smithy for sharpening picks, &c., and a workshop for repairing tubs if space is available; but none of these erections should in any way interfere with the view of the winding engineman, which must be clear and uninterrupted, so that he can watch the cages as they come up the pit.

The "tippler," "tumbler," or "kick-up" is a contrivance for facilitating the discharge of the coal out of the tub on to the screen; it is placed close to the top of the screen and the tub on being pushed into it, in some cases turns right over and in others sufficiently so to allow the coals to pass gently into the screen. The attendant afterwards easily puts it into its original position and returns to the shaft with the empty tub.

A recently improved patent kick-up works automatically, and may be associated with a self-indicating weighing machine. The tub on entering the tumbler causes the weighing machine to register its weight and directly afterwards turns over, shoots out the coals, and returns to its usual position. The weight of empty tub is then registered and deducted from the previously taken gross weight. The self-righting tippler is so made as to allow the full tub to follow in and push the empty forward as it enters. A vessel is attached to the bottom of the kick-up in which is placed a liquid, the weight of which is sufficient to cause the tub to right itself. It thus gives the kick-up its automatic action. The tub turns over side-ways, not end-ways as is usual.

In placing the upright columns which carry the stage, care should be taken that they rest on a solid foundation of stone and that they are well arranged, and with at least $2\frac{1}{2}$ feet clear space between them and the side of the waggons while being loaded under the screens, so as to avoid accidents. The floor about the railway under the screens may be paved to enable the coal to be swept up unless the pipes, &c., laid, render it inadvisable. If more than one screen is erected to load on the same line there should be sufficient space between them to allow for the largest railway wagons. The length and pitch of the screen will depend on circumstances—the size, quality and freedom from impurities in the coal raised. A very usual pitch is 1 in 2. The sides are usually of wood or iron, the bottoms of cast iron plates. There should be a slight fall from the shaft to the screens. The screen bars may be of wrought-iron or steel and are usually placed to have from $\frac{1}{4}$ to $1\frac{1}{2}$ inch space between them, according to the circumstances of the colliery. The railways about the screens should be laid at such gradients that empty wagons will, by gravity, quietly move under, and loaded wagons move away from the screens on being started. The greatest difficulty in the matter is, that if the gradients are suitable for good weather, they are certain to be too flat for winter during frost and snow; if they are made to suit winter weather, they are too steep in good weather or during rain, and entail much labour in either pushing, or braking and spragging in these extreme seasons. Some wagons run much better than others, so that an inclination suitable to one may not answer so well for another. It is usual to adopt an inclination of from $\frac{3}{8}$ths of an inch to $\frac{1}{2}$ an inch per yard.

Where greater facilities are required for cleaning and preparing different kinds of coal and of various sizes, such as nuts, beans, peas, small, duff, &c., more elaborate arrangements are provided, which are worked by machinery,

such as revolving riddles, moving bands, vibrating screens, and cleaning tables. There should be 6 feet of space between each line of railway, and sufficient siding accommodation for empties and also for loaded wagons for one day's work.

Winding Engine.—One of the most important of the surface arrangements is the winding-engine, which is vertical, horizontal, single, or double ; it may be a beam engine or geared. The horizontal, direct-acting coupled engines are unquestionably the best. A single engine causes delay and is an annoyance when it gets on "centre" and every part of the horizontal engine is more open to inspection by the engineman, than the vertical ; is easier cleaned, oiled, and repaired. With 60-foot high pulley frames there should be not less than 20 yards between the centre of the drum and the centre of pit, but with higher pulley-frames the distance must be proportionately greater. The under rope of the drum is subject to more strain than the other because it is bent one way in coiling on the drum and another in passing round the pulley.

A few winding engines are condensing, but this arrangement is not easy of application, owing to the rapidity of winding and the frequent stoppages and startings. Occasionally winding-engines work expansively, but the intermittent working of the engines prevents a more general adoption of this plan, though condensing and expansion both help to economise fuel. Compound engines have in a few instances been applied to wind coal. The Great Western Colliery Co. are about to erect compound engines to wind coal at one of their shafts near Pontypridd, the steam for which will be supplied by Lancashire boilers working at 120 lbs. pressure. A higher steam pressure than formerly prevails ; 60 lbs. being a very common steam pressure, and modern Lancashire boilers are made to work at or above 100 lbs. The length of the cylinder is about double its diameter and is then considered to be well proportioned. The best position for the winding-engine is on a level with the stage top where the tubs are pulled out of the cages, or but slightly above that level as it thus affords the engineman on duty a clear and uninterrupted view of the pit top. It should never be placed below the stage level. The cylinders of the winding-engine should in all cases be behind the drum, so that when the engineman is at the handles, all parts of the machinery are before him as he looks towards the pit top. The drum for a round rope may be either plain, conical or spiral. André gives the following rule for plain cylindrical winding drums. Assuming 10 feet to be the minimum diameter for a wire rope 1 inch in circumference, add 6 inches to the diameter of the drum for every increase of $\frac{1}{4}$ of an inch in the circumference of the rope. Thus a $4\frac{1}{4}$ inch circumference rope will require a drum 10 feet + 6 feet 6 inches = 16 feet 6 inches in diameter. At very great depths there is a disadvantage in having the drum excessively large, for owing to the inertia at the lift the power required is much in excess of that during the latter part of the ascent of the load. This fact has led to the introduction of conical and spiral drums, so as to equalise, at least to some extent, the strain on the engine.

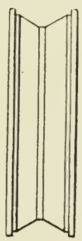


Fig. 59.—Cone Drum.

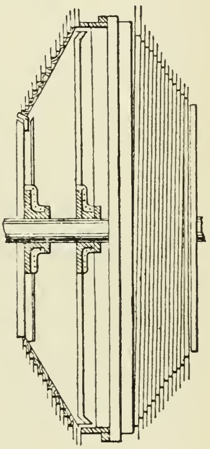


Fig. 60.—Scroll or Spiral Drum.

In conical and spiral or scroll drums shown at Figs. 59 and 60 respectively, the diameter of the drum is least when the engine lifts the load and increases as the cage advances up the shaft. There is an objection to the cone drum, because the rope is liable to slip on it. A spiral drum should have considerable

difference in its diameters at the beginning and end of the winding, and to avoid liability of slipping, the last few coils of the rope in the winding should lap on a plain part of the drum as shown on the sketch given. The spiral drum is the most perfect form of counterbalancing known, but is enormously heavy and costly, and unless for very deep shafts, these disadvantages will outweigh the advantage gained by its counterbalancing effect.

In winding-engines having cylinders of 25 inches in diameter and upwards, Cornish double beat valves, being more easily worked, are preferable to the slide valve, with which, unless it is balanced by a special arrangement, there is much friction, consequently the engine becomes unwieldy, and there is a difficulty in reversing it with the steam on. The Cornish valve may be opened and closed and put into any position with ease without special appliance.

Connected with the crank shaft either directly or by means of gearing is the drum for winding, the eccentrics for working the valves in the steam chest placed alongside the cylinder and, usually, the indicator which shows the engineman the position of the cages in the shaft is worked off the crank shaft itself. The throttle valve is usually placed immediately under the engineman and by means of a handle communicating with the valve, he is able to turn the steam into the engine or to stop its entry at pleasure. Another handle near him communicates with the reversing gear, and a foot brake is generally attached to the drum, but sometimes a steam brake is applied in preference. A stuffing box with gland in the end of the cylinder, prevents the escape of steam there, as the piston rod works through the gland.

A simple form of automatic brake has been devised to prevent overwinding. At a point, which the cage, in its ascent, ought not to reach when under proper control, are placed levers overhanging the shaft. The cage, on striking these levers, puts into action a steam brake which acts directly on the drum.

Fig. 61 represents a pair of high-pressure winding-engines as made by Messrs. Thornewill & Warham, Engineers, of Burton-on-Trent. The cylinders are 26 inches in diameter with a 5-foot stroke, the winding-drum being of cast iron.

The cylinders are bolted and keyed to planed facings on the bed-plates, the covers being fitted with glands and stuffing-boxes, brass-bushed and provided with square-threaded gland-bolts and nuts. The covers are well stiffened and have an ample number of joint-bolts and studs.

Branches are cast on the cylinder to receive the nozzle boxes, each having fitted one steam- and one exhaust-valve, both being Cornish double-beat valves made of gun-metal, with stems of steel or phosphor-bronze, and are fitted with bridles to receive the lifting-cams on the rock-shafts which are operated by the link motion. The reversing motion shown is of the shifting-link type, but the Gooch and Allan link motions are fitted when preferred. The rods and shafts are of best iron, and the pins, links, and dies are of steel; the eccentrics and straps are of best cylinder metal.

The pistons are of cast iron of box section, and packed with Oldham's or other makers' special rings if required; the piston-rods are of mild steel, the cross-heads of hammered iron with steel gudgeons; the connecting-rods of hammered iron fitted with brasses, straps, gibs and cottars; the cranks of hammered iron with steel pins, and are shrunk when hot and afterwards keyed on the crank-shaft which is preferably of best hammered scrap-iron.

The guide-bars and blocks are of cast-iron, planed and having means for adjustment when worn.

The bed-plate is of hollow box section, well ribbed, and having facings to receive the various mountings.

The main bearings are fitted with heavy gun-metal steps secured by iron caps and bolts.

The winding-indicator consists of a cast-iron open-fronted column containing

a long screwed spindle on which is a nut with a finger. The lower end of the column is bolted to the engine bed-plate, and is fitted with a pair of bevel wheels, one of which is keyed on the small drag-shaft driven off the main crank-pin, and

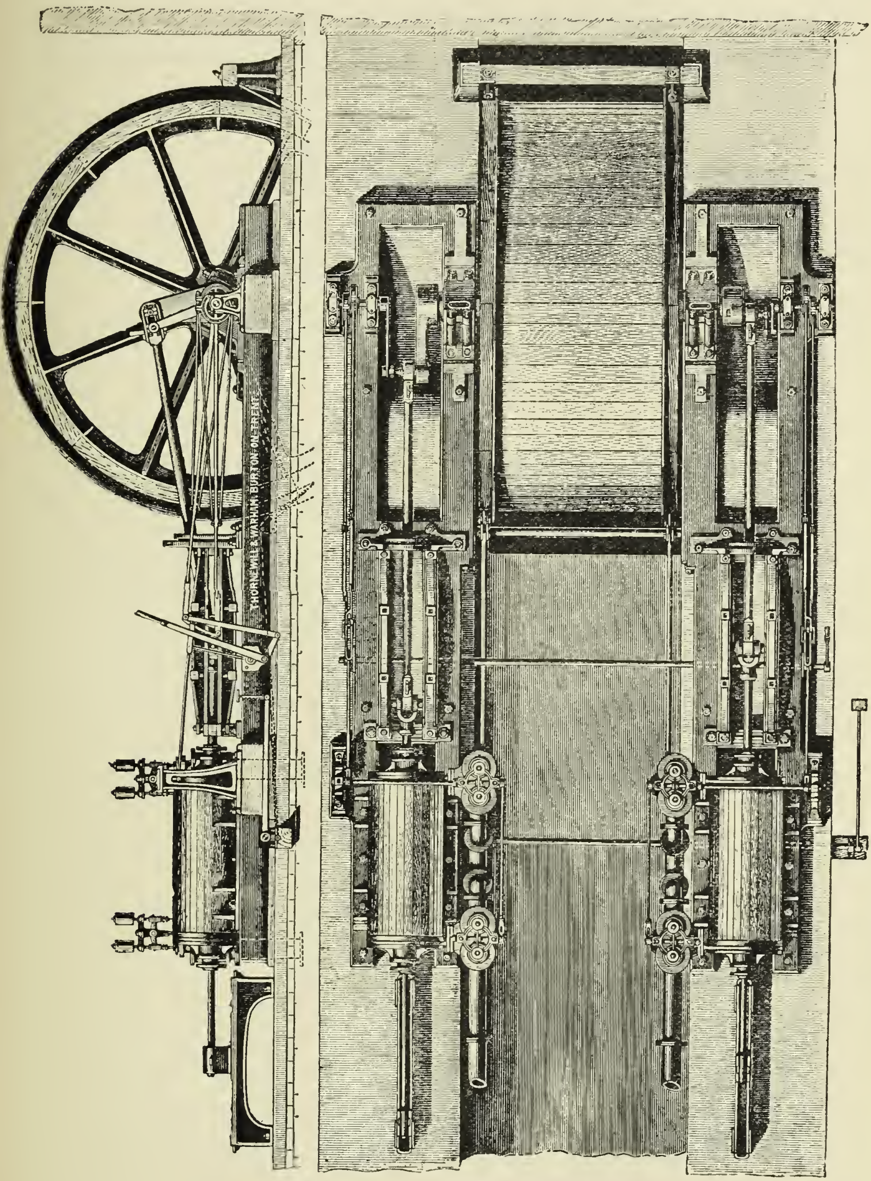


Fig. 61.—Pair of High-pressure Winding-engines as made by Messrs. Thornewill & Warham.

the other to the upright screwed spindle. The nut is prevented from turning round by having a projection fitting into the open front of column, and when the screw is rotated, the nut travels upwards or downwards along the slot in the column. A gong is fitted at each end of the nut's traverse, so that the nut-finger

may give notice by striking the bell when the cage is a pre-determined distance from the end of its journey. This is a positive indicator, and is superior to any type depending on cords, chains, or clock-faced dials.

The drum has three "centres" to support the wood-lagging, and all are firmly keyed to the crank-shaft.

A brake, having two straps with the necessary connections, is fitted, and the reversing-handle, throttle-valve-handle, and brake-treadle, are arranged conveniently for the engineman.

All the parts are machined, and the necessary portions of the engine polished. The cylinders are clothed with non-conducting composition and mahogany lagging strips secured by polished brass bands.

All holding-down bolts are supplied, and also steam and exhaust-pipe connections to the outside of the engine-house.

The timber and labour for drum and brake-laggings are usually provided by the purchaser, but the contractor turns up the laggings after they have been fitted.

Engines are now being fitted with wrought-iron built drums; being much lighter than cast-iron they enable the engines to start more quickly and work more rapidly.

When automatic expansion is desirable it is usual to fit a tumbler to each steam-valve spindle swinging on a pin kept up to its position by a spring. The tumbler has an arm which comes into contact with a cam, the position of which is regulated by the governor that disengages the tumbler-toe from the steam-lifter on the rock-shaft; the steam-valve and spindle are then free to fall, the rate of descent being controlled by a dash-pot fitted with an adjustable valve.

COUNTERBALANCING.—In all cases of winding coal up vertical shafts with drums of equal diameters, a great disadvantage arises from the fact that the working strain is much greater on the engine at the commencement than at the end of winding.

Frequently, where the shaft is deep, the load at the "lift" is doubled, because the weight of the rope exceeds that of the coals, tubs, and cage, to be drawn up. Different methods of counterbalancing, with a view of assisting the winding-engine at the commencement of the wind, have been adopted at different times, some of which are as follow:—

Rope balance.—This consists of a tail-rope attached to the cages in the shaft. It is fastened to the bottom part of the cage at the surface and is conveyed to a point below the loading-stage in the pit, where it passes round a pulley and then up to the other cage, under which it is secured. The object sought by this method is to make the load uniform; when the cage is lifted from the shaft bottom, the weight of the ropes in the shaft balance each other, and will continue to do so throughout the wind. An objection to the tail-rope in the shaft is the extra strain on the capping of the ropes.

Another method is by a *pendulum counterbalance*, which, however, is only applicable to shallow shafts, where the necessity for counterbalancing is not urgent. A weighted pendulum is raised by a chain attached to a drum on the shaft of the winding-engine. At the commencement of winding this pendulum is in a horizontal position, and therefore the full weight is acting to aid the engine against the load. As the winding proceeds to half-winding an increasing portion of the weight is supported by the rod, which at half-winding is in a perpendicular position, and then as the load is brought to the surface the rod returns to a horizontal position, the weight thus acting against the engine with increasing force during the last half-winding.

A third method consists in a *counterbalance chain*, see Fig. 62, which is frequently applied with very good results to assist the winding-engine. This requires a separate pit or well about 50 yards deep for the chain to work in. A

rope is fixed to the drum-shaft of the engine and to the balance-chain in the small pit. The balance-chain would be 50 yards long, and is so arranged that with one cage at the surface and the other at the shaft bottom the whole length of chain is hanging in the small pit. The rope by which it is wound up allows the whole of the balance-chain to rest upon the small pit bottom when the ascending and descending cages meet in the shaft. The rope passes over the drum-shaft in a contrary direction to the drawing-rope.

Other methods of counterbalancing are by using the cone and scroll drums in preference to plain or cylindrical drums, and these have already been alluded to.

A plain conical drum, to be effective as a counterbalance, requires an angle so great as to be dangerous on account of the liability of the rope to slip. Any advantage to be derived from having a safe angle being trifling, it is really not worth the risk.

Rule 29 of the Mines Act, 1887, renders the use of flanges or horns to the drum compulsory, and if the drum is conical, there must be appliances sufficient to prevent the rope from slipping.

MISCELLANEOUS.—In laying out the surface arrangements, a considerable amount of thought is necessary to ensure a thoroughly satisfactory and economical working after completion. The particular circumstances and requirements of each colliery must be thoroughly mastered in order to design an effective scheme. The engines and buildings must be adapted to their work, and after the coal is brought to the surface every operation connected with its weighing, screening, cleaning, and after-disposal, should be calculated to give as little manual labour as possible in working, and at the same time yield the various sizes of coal in a good, clean, and marketable condition.

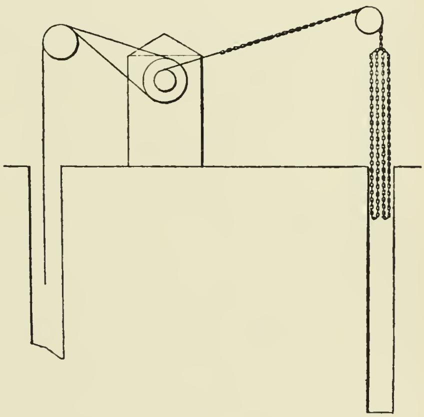


Fig. 62.—COUNTERBALANCE CHAIN FOR WINDING.

A carelessly laid out bank top renders it necessary to keep employed a large number of workmen to deal with the daily out-put, and thus add to the cost of production. In times of keen competition even a penny extra cost on the tonnage price in raising the coal may place a colliery at a disadvantage as compared with a neighbouring one, and result in loss of contracts; with greatly increased cost prices, it may be impossible to work the colliery at all.

Mr. C. M. Percy, in his excellent work on *The Mechanical Engineering of Collieries*, gives the following rules for winding engines. (1) To find the load which a given pair of engines will start. Multiply the area of one cylinder by the pressure of steam and twice the length of stroke. Divide this by circumference of drum and deduct $\frac{1}{3}$ for friction, &c. The result is the load the engines can start. For instance, 2 — 20-inch diameter cylinders by 40-inch stroke, with a 12-foot diameter drum and the steam pressure at boilers 50 lbs. $\frac{314 \times 50 \times 80}{454 \text{ in.}} = 2{,}766 - \frac{1}{3}$ or $922 = 1{,}844$ lbs. the load. N.B.—The load referred to in this and the next rule comprises rope and coal, because cages and tubs balance each other. (2) Knowing the load and the diameter of drum and

the length of stroke and the pressure of steam, to find the area and diameter of cylinders. Multiply the load by the circumference of the drum and add $\frac{1}{2}$ for friction, &c. Divide this by the steam pressure multiplied by twice the length of stroke, and the result is the area of the cylinder. Example, a drum 15 feet, stroke 6 feet, the steam pressure 60 lbs., and the load 7 tons = 15,680 lbs. $15{,}680 \times 47 = 736{,}960 + \frac{1}{2}$ or $368{,}480 = 1{,}105{,}440$. $\frac{1{,}105{,}440}{60 \times 6 \times 2} = 1{,}535$ square inches, area of piston, and to find the diameter we must divide the area by ·7854 and take the square root of the result, thus $\sqrt{\frac{1{,}535}{\cdot 7854}} = 44\frac{1}{4}$ inches diameter of cylinder. (3) To find the period of a winding approximately. Reckon the piston to travel at an average velocity of 400 feet per minute, and divide this by twice the length of the stroke, and multiply by circumference of drum. This gives speed of cage in feet per minute, and divide depth of pit by this, and the result gives period of a winding. Example, drum 47 feet circumference, stroke 6 feet, depth of pit 600 yards $= \frac{400}{6 \times 2} \times 47 = 1{,}565\cdot 1$, speed of cages in shaft per minute $\frac{600 \times 3}{1{,}565} = 1\cdot 15$ minute or about $1\frac{1}{7}$ minutes. (4) To find the *useful* horse-power during a winding. Multiply the depth of pit by weight of coal raised, and divide this by period in minutes occupied in winding, and divide again by 33,000. Example, coal 2 tons = 4,480 lbs., depth 1,500 feet, period of winding $\frac{5}{6}$ths of a minute; $\frac{1{,}500 \times 4{,}480}{\frac{5}{6} \times 33{,}000} = 244$ horse-power. (5) To find the approximate horse-power exerted by a pair of winding engines during a winding. Multiply area of both cylinders by $\frac{2}{3}$rds of the boiler pressure of steam and by 400, and divide by 33,000. Example, cylinders 30 inches diameter = 706 square inches, boiler pressure 60 lbs., $\frac{2}{3}$rds of which is 40. $\frac{706 \times 2 \times 40 \times 400}{33{,}000} = 685$ horse-power. (6) To ascertain the piston-speed of a winding engine. Divide the windings into periods of 3 revolutions each. Let two persons take alternately the time in seconds which each 3 revolutions occupy. Take the average from these as follows:—Suppose there are thirty revolutions divided into 10 periods, three revolutions each, the time occupied in seconds comes out 9, 7, 5, 3, 2, 2, 2, 3, 6, 9 = 48 seconds for the whole winding. Suppose the stroke 5 feet $\times$ 2 = 10 $\times$ 30 = 300 piston feet in 48 seconds and 300 $\times$ 60 = 18,000 $\div$ 48 = 375 piston feet per minute.

If only the average piston speed throughout the wind is required, there is no useful object attained by dividing the winding into periods of a certain number of revolutions. The whole winding may in that case be timed, and the number of seconds occupied in the wind be divided into twice the length of stroke multiplied by the number of revolutions. Where a comparison of different rates of the varying piston speed throughout a wind is desired, it would, of course, be necessary to sub-divide the total revolutions.

It will be well to bear in mind the following rules for winding engines:—

$$\text{Horse-power} = \frac{\text{area of cylinder} \times \text{effective pressure per square inch} \times \text{piston speed feet per min.}}{33{,}000}$$

$$\text{Area of cylinder} = \frac{\text{Horse-power} \times 33{,}000}{\text{Effective pressure per square inch} \times \text{piston speed in feet per minute.}}$$

$$\text{Effective pressure per square inch} = \frac{\text{Horse-power} \times 33{,}000}{\text{Area of cylinder} \times \text{piston speed in feet per minute.}}$$

$$\text{Piston speed in feet per minute} = \frac{\text{Horse-power} \times 33{,}000}{\text{Area of cylinder} \times \text{effective pressure per square inch.}}$$

Horse-power is the term used to denote the work performed by mechanical appliances, and one horse-power is equal to raising 33,000 lbs. 1 foot high in 1 minute.

A few questions on winding engines, &c., such as are given at the examinations, are now submitted, and the method of working out answers to them shown.

Question 2.—What size and kind of engines would you fix to raise 1,000 tons of coal from a depth of 500 yards in 8 hours? Describe the size of ropes, description of cage, diameter of drum, pressure of steam, time of drawing and changing, the number of tubs wound at each time and weight of each?

1,000 tons of coal per day of 8 hours $= \frac{1{,}000}{8} = 125$ tons per hour : $\frac{125}{60} =$ 2·08 tons per minute, and assume that for this large quantity the seam is a thick one, capable of taking large tubs, and that the cage will have an average running speed of 1,000 feet per minute inclusive of the stoppages to change tubs; then we have $\frac{500 \times 3}{1{,}000} = 1\cdot5$ minute as the time in which we must make each trip, that is, a cage comes to the surface every $1\frac{1}{2}$ minutes; then as 2·08 tons per minute must be landed in order to get 1,000 tons in 8 hours, we have $2\cdot08 \times 1\cdot5 = 3\cdot12$ tons to be drawn in each cage. Unless trams carrying over 30 cwt. be used, it would be necessary to have double-decked, or if very small trams are used, three-decked cages, but assume that double-decked cages are to be used, with 2 tubs in each deck, or 4 tubs per cage, which gives an average of $\frac{3\cdot12}{4} = \cdot78$ ton or 15·6 cwt. of coal per tub. Tubs weigh from $\frac{1}{3}$ to $\frac{1}{2}$ their carrying capacity, and a tub to carry this weight need not weigh more than 7 cwts. As the depth is great and the weight for the engine to lift from the pit bottom must necessarily be considerable, steel should be used wherever possible in order to keep down the dead weight. The tubs and cages may be of steel, and the rope of steel wire.

Now to consider the strength of the rope required, the weight upon which at the start would be somewhat as follows:—

One steel cage and chains, say	2 tons,	5 cwt.
Coal in 4 tubs = ·78 ton × 4 =	3 ,,	2·4 ,,
4 empty steel tubs = 4 × 7 cwt. =	1 ,,	8 ,,
	6 ,,	15·4 besides its own

weight. The weight of 250 fathoms (or really rather more as there is the height of the pulleys above the top of the pit) at say roughly 14 lbs. per fathom would be 1 ton 11 cwt., to add to 6 tons 15·4 cwt., making a total of 8 tons 6·4 cwt., so that by estimating for a rope having a safe working load of 8·4 tons, we shall be quite safe. By the formula already given to find the safe working load of a steel

wire rope we have—Circumference = $\sqrt{2 \cdot 4 \times 8 \cdot 4} = 4\frac{1}{2}$ inches, which is the circumference of the steel rope required. Applying the formula given to find the size of drum, it gives 17 feet as the diameter for a plain cylindrical one. The engine must necessarily be powerful enough to lift 8 tons 6·4 cwt., therefore assume it has a 6-foot stroke, and a piston speed of 400 feet per minute. In that case $\frac{400}{6 \times 2} = 33 \cdot \dot{3}$ strokes per minute, and $33 \cdot \dot{3} \times 17 \times 3 \cdot 14159 = 1{,}780$ feet per minute, the average speed of the cage whilst travelling from bottom to the top of pit. Therefore $\frac{500 \times 3 \times 60}{1{,}780}$ = say 51 seconds, nearly as the time occupied in the journey stated. It has already been ascertained that a cage must be drawn every 1·5 minute, or 90 seconds, in order to raise the desired quantity. There would therefore be $90 - 51 = 39$ seconds as the time in which to do the changing. To find the size of cylinder according to Mr. Percy's rule already given, assuming a boiler pressure of 60 lbs., we have as the circumference of a 17-foot diameter drum 53·4 feet, and the stroke being 6 feet, this gives 12 feet travel of piston. The weight of cages and tubs balance each other and are not to be considered, but the weight of coal is 3 tons 2·4 cwt., that of the rope 1 ton 11 cwt., making a total of 4 tons 13·4 cwt., or say $4\frac{3}{4}$ tons.

The weight or resistance of $4\frac{3}{4}$ tons at the end of a lever 53·4 feet long will be $4 \cdot 75 \times 53 \cdot 4 = 253 \cdot 65$ tons = 568,176 lbs., and the power to overcome this will be 12 (twice the length of stroke in feet) × 60 (the boiler pressure of steam) = 720 × something which will equal 568,176. Therefore $\frac{568{,}176}{720} = 789$, and this means the area of the piston in square inches. Add one-half for overcoming friction, $789 + 394 \cdot 5 = 1{,}183 \cdot 5$ square inches area of piston, and therefore $\sqrt{\frac{1{,}183 \cdot 5}{\cdot 7854}} = 38 \cdot 82$ inches, or say 39 inches as the diameter. Inasmuch as at the lift only 1 cylinder may be applied, this size of engine is necessary. For reasons already given the engines should be placed horizontally, and have Cornish in preference to slide valves, and as has been shown with 2 cylinders of 39 inches diameter, 6 feet length of stroke, $33 \cdot \dot{3}$ revolutions per minute (average velocity), effective steam pressure 40 lbs., and 17 feet diameter of drum. The cages to be double-decked and made of steel, to hold 2 tubs on each deck. Time of drawing 51 seconds, of changing 39 seconds, the weight of steel tubs 7 cwt. each when empty, and the circumference of the steel wire rope to be $4\frac{1}{2}$ inches.

Question 3.—What description and size of winding engines would you erect to raise 100 tons per hour from a coal-field 2,000 acres in extent, the seam being 5 feet 6 inches thick, and the depth of shaft 300 yards?

I should fix a double horizontal engine as in the last case, direct acting, and to find the size should proceed much in the same way. 100 tons per hour = $\frac{100}{60} = 1 \cdot \dot{6}$ ton per minute, or $1\frac{2}{3}$ tons, and on the same principle we should make a trip $\frac{300 \times 3}{1{,}000}$ = every $\frac{9}{10}$ths of a minute. $\therefore 1\frac{2}{3} \times \frac{9}{10} = 1\frac{1}{2}$ tons to be drawn in each cage. We should have to choose between sending this $1\frac{1}{2}$ tons in 4 tubs of $7\frac{1}{2}$ cwt. each, or in 2 tubs holding 15 cwt. each, or in 1 tub holding the 30 cwt. The seam is high enough for all sizes, but assume that 4 tubs are sent in a double-decked cage. The tubs when empty would weigh about 4 cwt. each, for that is about one-half of their carrying capacity, and the cage and chains about a ton, or

24 cwt., assuming that iron tubs, an iron cage, and an iron wire rope be used. The weight the engine would have to lift would be—

Cage and chains, say	1 ton 4 cwt.	
Coal in 4 tubs	1 „ 10 „	
4 empty tubs = 4 × 4 cwt.	„ 16 „	
	3 „ 10 „	besides the weight

of rope. The weight of 150 fathoms of iron wire rope at say roughly 14 lbs. per fathom, would be nearly 1 ton, and 1 ton + 3 tons 10 cwt. = $4\frac{1}{2}$ tons as a safe working load for the rope. Circumference = $\sqrt{4 \times 4\frac{1}{2}} = 4\frac{1}{4}$ inches as the circumference of iron wire rope necessary.

Assume a 16-foot diameter drum (Mr. André's rule would give 16 feet 6 inches), and also that the engine has a 5-foot stroke, with a boiler pressure of steam of 60 lbs., the piston speed being 400 feet per minute, $\frac{400}{5 \times 2} = 40$ strokes per minute. $40 \times 16 \times 3{\cdot}14159 = 2{,}010$ feet per minute as the average speed of the cage whilst travelling from bottom to top of pit. $\frac{300 \times 3 \times 60}{2{,}010} =$ nearly 27 seconds. As a trip must be made every $\frac{9}{10}$ths of a minute = 54 seconds, this leaves 54 — 27 = 27 seconds in which to do the changing.

To find the size of cylinder we have the weight of coal and rope at $2\frac{1}{2}$ tons. $\frac{50{\cdot}26 \times 2\frac{1}{2} \times 2{,}240}{5 \times 2 \times 60} = 469{\cdot}09 + 234{\cdot}54$ for friction $= 703{\cdot}63$ and $\sqrt{\frac{703{\cdot}63}{{\cdot}7854}} =$ 29·93, or say 30 inches as the diameter of the cylinders.

Question 4.—What is meant by such expressions in machinery as horse-power, units of work, and back-pressure of the steam?

The English unit of work is the power necessary to raise one pound through a space of one foot; in other words, it is 1 lb. raised 1 foot high in 1 minute. It is assumed that a horse will raise 33,000 lbs. 1 foot high in 1 minute, therefore we call one horse-power, 33,000 lbs. raised 1 foot high in 1 minute. Back pressure of the steam is the resistance the piston of an engine meets with from the spent steam as it is forced into the exhaust port, and its tendency is to lessen the effect of the engine.

Question 5.—What is meant by the duty of an engine?

The amount of work yielded by that engine, or the number of lbs. raised 1 foot high by the combustion of a given quantity of coals.

Question 6.—Why is a machine put in motion by steam?

Because the pressure of the steam on being applied to the piston of the engine is greater than the combined resistance offered by the weight attached and the friction of the engine itself.

Question 7.—What is steam and how is it obtained? What do we mean by such expressions as high pressure and low pressure steam?

Steam is an invisible elastic fluid, generated from water by the application of heat. It is measured by pressure gauges, and we speak of it as being so many pounds pressure to the square inch. We also speak of steam having a pressure

of 15 lbs. to the square inch as one atmospheric pressure; 30 lbs. as two atmospheres, 45 lbs. as three atmospheres, and so on. Steam of two atmospheres and above is called high pressure steam, and below two atmospheres, low pressure steam.

Question 8.—Describe an experiment for ascertaining approximately the relation between the pressure and temperature of steam at a moderate pressure above that of the atmosphere.

This experiment can be made by means of a Marcet's boiler, see Fig. 63. The apparatus consists of a vessel in which is first placed a little mercury, G, and above the mercury a small quantity of water, F; above the surface of the water a space is left for the steam. A piece of glass tube, A, about a yard long, and open at both ends, is passed steam tight through the top of the boiler, and reaches nearly, but not quite, to the bottom, so as to be well into the mercury. It is placed in an upright position. Similarly, a thermometer, C, is passed through the top of the boiler, but its bulb does not quite reach the surface of the water. The glass tube is furnished with a graduated scale, B, placed outside the boiler, by means of which the height of mercury in the tube above that in the boiler can be read off approximately. A cock, D, is also placed outside the boiler, above the surface of the water, so that when it is opened the enclosed air may be driven out through it by the steam. The boiler being placed conveniently for the purpose, a Bunsen flame, K, is applied under it, causing the water to boil and generate steam.

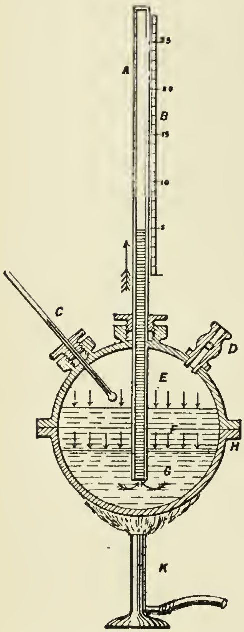


Fig. 63.—Marcet's Boiler.

On this steam attaining a greater pressure than the pressure of the external air, the mercury will begin to rise in the tube. By opening the cock for a short time the steam will drive out the enclosed air from the boiler, and the cock may be shut again. As the pressure of the steam above the atmosphere increases, it will be noticed that the mercury rises in the tube, and at the same time that the temperature of the steam also rises above 212° F., as seen on the thermometer.

The cock must now be carefully adjusted so as to allow the exact quantity of steam being generated in a certain time to pass through it to the outer air, in the same time.

The temperature and the pressure corresponding to that temperature will then be constant, and may be read off and recorded from their respective scales.

By closing the cock again, the temperature may be allowed to rise, say, 10°, upon reaching which the cock is again adjusted as before, and the temperature and pressure again noted. This operation may be repeated for any reasonable number of times, and it will be seen that for a given temperature there is a corresponding pressure, or vice versâ.

When the temperature is 233° F. the corresponding pressure will be 7·4 lbs., half an atmosphere, or 22 lbs. absolute, for the mercury will have risen to 15 inches.

At a temperature of 250° F. the mercury will have risen to about 30 inches, corresponding to a pressure of 14·7 lbs. on the square inch, or 1 atmosphere, or 29·4 lbs. absolute.

Further experiment would be impracticable, as the height of the glass tube, and the amount of mercury in the boiler limit the proceeding. Mercurial gauges on this principle were at one time used to register the pressure of the steam in boilers, before Bourdon's gauge was introduced.

Question 9.—What are *saturated*, *superheated*, and *wet* steam respectively? Define a thermal unit, and explain what is meant by the latent heat of steam.

Saturated steam is steam in contact with the water from which it is generated. It is at its greatest density corresponding to the temperature and pressure at which it is formed. Its physical condition is such, that at the slightest increase of pressure or decrease of temperature it is ready to yield some portion of liquid. For a given pressure there is one temperature and one density. The steam usually supplied to engines from ordinary boilers is what is called *saturated* steam.

Superheated steam is saturated steam which has received an additional quantity of heat after it is free from contact with the water. It has a higher temperature than that corresponding to its pressure, consequently, when used in the cylinders of an engine, no liquefaction takes place, for although superheated steam may lose heat in the cylinder, its temperature never falls so low as the temperature of saturation. Superheated steam is not now used in the cylinder, however, owing to many practical objections.

Wet steam is steam containing water. Steam in this condition is sent to the cylinders of an engine through "priming" at the boilers. Some boilers are liable to "prime," the chief causes giving rise to it being, small steam space in the boilers, and also a bad circulation of water. The loss of efficiency in using it arises from the fact that the water carried into the cylinder produces no pressure on the piston, and does no work. Whilst in the cylinder it condenses the freshly entering steam, so that there is a loss from waste of heat.

The British thermal unit is the heat necessary to raise 1 lb. of water by 1° F., when at its maximum density, *i.e.*, from 39·1° to 40·1° F.

Latent heat is the quantity of heat communicated to a substance in a given state in order to convert it to another state without changing its temperature. The latent heat of steam is the heat necessary to convert water at the boiling point (which varies with the pressure) into steam without changing its temperature. Latent heat is not sensible to the thermometer, and is measured in a special manner. The latent heat of steam at atmospheric pressure is found to be 966·6. That is, it requires 966·6 thermal units of heat to convert 1 lb. of water at 212° F. into steam at the same temperature, or 1 lb. of steam at 212° F. gives out 966·6 thermal units of heat in being condensed into water at the same temperature.

Question 10.—If one pound of coal develops 12,000 units of heat by its complete combustion, how much water at 60° F. should be converted into steam at 212° by the consumption of one cwt. of such fuel, assuming that there is no loss of heat during the operation?

The total heat of evaporation is the sum of the sensible and latent heats of evaporation. The heat necessary to raise the temperature of 1 lb. of water from the freezing point, 32° F., to the temperature of evaporation is called the sensible heat, and the additional heat necessary to evaporate it is termed the latent heat.

The total heat of evaporation for water is the number of thermal units required to raise 1 lb. of water from the freezing point, 32° F., to the stated temperature at which it is being evaporated, and to evaporate it at that temperature.

Hence the total heat in 1 lb. of steam = $966 \cdot 6 + (212^\circ - 32^\circ) = 1{,}146 \cdot 6^\circ$.

As the water is at 60° F., the units of heat required to convert it into steam will be $1{,}146 \cdot 6^\circ - (60^\circ - 32^\circ) = 1{,}118 \cdot 6^\circ$ F. Or $966 \cdot 6^\circ + (212^\circ - 60^\circ)$.

If one pound of coal gives 12,000 units of heat, one cwt. will give $12{,}000 \times 112 = 1{,}344{,}000$ units.

Therefore the water converted into steam will be $\frac{1{,}344{,}000}{1{,}118 \cdot 6} = 1{,}201 \cdot 5$ lbs.

Question 11.—Describe condensing and non-condensing, high-pressure and low-pressure, horizontal and vertical, expansive and non-expansive, direct-acting and geared, single and double engines?

A high-pressure engine is one working with steam of 30 lbs. absolute pressure to the square inch or above, but as its exhaust is open to the atmosphere, it is opposed by the atmospheric pressure of 15 lbs. to the square inch, and its effective pressure is thereby reduced 15 lbs. to the square inch.

A low-pressure engine works with steam below 30 lbs. pressure absolute (or 15 lbs. above atmospheric pressure) to the square inch, and may or may not have a condenser for receiving the exhaust steam. A condensing engine has a condenser and air-pump connected with it, and the steam having performed its work in the cylinder, is admitted to the condenser, where it is condensed by coming into contact with a scattered jet of cold water which meets it there, and the condensed steam and water then fall to the bottom of the condenser. All water contains air more or less, and the heat of the steam disengages the air from the condensing water, which would rise through the exhaust pipe and so prevent the proper escape of steam as well as counteract its pressure, if provision were not made for its disposal otherwise. This disposal is by means of the air-pump, which pumps out the condensed water and air, thus preventing the air from accumulating in the condenser, where it would obstruct the engine. But the air-pump does not effectually remove the condensed water and air; if it did, and all the exhaust steam from the cylinder were condensed, a perfect vacuum would be formed; as a matter of fact this is never attained in practice, but there always remains in the cylinder a portion of uncondensed steam; the resistance from this is frequently equal to 4 lbs., and is termed the back pressure. With 4 lbs. of back pressure we should have 11 lbs. of vacuum, because 15 lbs. (the atmospheric pressure) — 4 lbs. = 11 lbs. So that with a given pressure of steam in the boiler we should have 11 lbs. more effective pressure per square inch on the piston of a condensing engine as compared with that on the piston of a high-pressure engine.

A non-condensing engine has no condenser, but exhausts its steam direct from the cylinder by means of pipes into the atmosphere. Horizontal and vertical engines, as the names imply, indicate whether the cylinders are placed vertically or horizontally. An expansive engine is one having an arrangement whereby the steam is cut off when a certain point of the stroke is reached, the stroke being completed by the elasticity of the steam already in the cylinder. In a non-expansive engine the initial pressure of the steam is maintained throughout the stroke, except in so far as it is not reduced by the throttle or steam valve, which reduction is termed "wire drawing." A direct-acting or first motion engine conveys motion to the main shaft direct by means of the crank, but in a geared engine spur and pinion wheels are used, which have the effect of reducing the speed of the drum, but increase the load the engine will lift. Sometimes a single cylinder is used, sometimes two working on the same shaft, and they are said to be single and double respectively.

Question 12.—Does the pressure on the piston increase or decrease during expansion? Explain the effect of using steam expansively? How is the mean pressure of the steam throughout the stroke ascertained?

The pressure of steam decreases on the piston during expansion. Mariotte's law with regard to the expansion of steam is as follows:—If a given weight of steam be made to vary its volume without changing its temperature, the elastic force of the steam will vary in the inverse ratio of the volume it is made to occupy.

Although there is a great economy in steam, and consequently in fuel, when using steam expansively, there is not actually more work done in a steam-engine working expansively, than where the same pressure is allowed to remain throughout the stroke. The advantage gained by expansion is the fact of getting more work out of a given quantity of steam. This may be explained by working out examples. The following is from *The Steam Engine*, by T. Baker. The rule to find the work done by expansion without the use of logarithms is this. Divide that part of the stroke through which expansion takes place into any even number of equal parts, and calculate the pressure per square inch upon the piston at each division of the stroke by Mariotte's law; take the sum of the extreme pressure in pounds per square inch, four times the sum of the even pressures, and twice the sum of the odd pressures; multiply the sum of all these by one-third of the common distance between the positions of the piston and the result will be the work done upon each square inch of the piston after expansion begins. The work done before expansion begins, being evidently equal to the pressure per square inch multiplied by the number of feet moved before expansion; and the whole work done during a single stroke is equal to the sum of the work done before and after expansion.

Example.—The pressure of steam upon the piston is 60 lbs. per square inch, the resistance arising from imperfect condensation is 4 lbs. per square inch, the length of the stroke is 12 feet, and the steam is cut off at $\frac{1}{6}$th of the stroke; it is required to determine the number of units of work done upon each square inch of the piston, the number of units of work gained by working expansively, and the load per square inch.

By dividing the remaining portion of the stroke after the steam is cut off, viz., $12 - 2 = 10$ feet into 10 equal parts, each will be a foot. Let the pressures at these different divisions be represented by p, p_1, p_2, p_3, &c., and then by Mariotte's law already given.

$$
\begin{aligned}
\text{As } 3:2 &:: 60:p_1 = 40 \\
4:2 &:: 60:p_2 = 30 \\
5:2 &:: 60:p_3 = 24 \\
6:2 &:: 60:p_4 = 20 \\
7:2 &:: 60:p_5 = 17{\cdot}142 \\
8:2 &:: 60:p_6 = 15 \\
9:2 &:: 60:p_7 = 13{\cdot}333 \\
10:2 &:: 60:p_8 = 12 \\
11:2 &:: 60:p_9 = 10{\cdot}909 \\
12:2 &:: 60:p_{10} = 10
\end{aligned}
$$

Then $60 + 10 = \underline{\underline{70}}$, the sum of extreme pressures.

$$
\begin{array}{r l}
40 & \\
24 & \\
17{\cdot}142 & \\
13{\cdot}333 & \\
10{\cdot}909 & \\
\hline
105{\cdot}384 & = \text{the sum of the even pressures.} \\
4 & \\
\hline
421{\cdot}536 & = 4 \text{ times the sum of the even pressures.} \\
\hline\hline
\end{array}
$$

$$\begin{array}{rl}
30 & \\
20 & \\
15 & \\
12 & \\
\hline
77 & = \text{the sum of the odd pressures.} \\
2 & \\
\hline
154 & = \text{twice the sum of the odd pressures.} \\
421{\cdot}536 & = 4 \text{ times the sum of the even pressures.} \\
70 & = \text{sum of the extreme pressures.} \\
\hline
3)645{\cdot}536 & \\
\hline
215{\cdot}178 & \\
120 & = 60 \times 2 = \text{work done before expansion.} \\
\hline
335{\cdot}178 & = \text{whole work done upon each square inch.}
\end{array}$$

Since the resistance from the uncondensed vapour is 4 lbs. per square inch, then $12 \times 4 = 48$ lbs. = whole resistance, and by subtracting this from 335·178, the whole work done per square inch there will remain $335{\cdot}178 - 48 = 287{\cdot}178$ for the effective work.

Now to find the advantage from working the steam expansively:—

When the steam works without expansion then $12 \times 60 = 720$ = work done upon each square inch, but as the steam is cut off at $\frac{1}{6}$th of the stroke in working it expansively, there is only $\frac{1}{6}$th of the quantity of steam used in this case, or $\frac{720}{6}$ = 120 lbs. per square inch, and $335{\cdot}178 - 120 = 215{\cdot}178$ lbs. gained in this case, or $\frac{335{\cdot}178}{120}$ = nearly 2·8 times as much work done by the same quantity of steam when worked expansively.

To ascertain the mean pressure throughout the stroke it is usual to divide its length into 10 even spaces and ascertain what the pressure would be at each division. An average of these gives the mean pressure on the piston throughout the stroke.

The even divisions will be $\frac{12}{10} = 1{\cdot}2$ foot apart. We may find the pressure at any point of expansion by Mariotte's law. Thus, the pressure of steam at 0 is 60 lbs.; at 1·2 foot it is 60 lbs.; at 2·4 feet it is $\frac{60 \times 2}{2{\cdot}4} = 50$ lbs.; at 3·6 feet it is $\frac{60 \times 2}{3{\cdot}6} = 33\frac{1}{3}$ lbs.; at 4·8 feet it is $\frac{60 \times 2}{4{\cdot}8} = 25$ lbs.; at 6 feet it is $\frac{60 \times 2}{6} = 20$ lbs.; at 7·2 feet it is $\frac{60 \times 2}{7{\cdot}2} = 16\frac{2}{3}$ lbs.; at 8·4 feet it is $\frac{60 \times 2}{8{\cdot}4} = 14\frac{2}{7}$ lbs.; at 9·6 feet it is $\frac{60 \times 2}{9{\cdot}6} = 12\frac{1}{2}$ lbs.; at 10·8 feet it is $\frac{60 \times 2}{10{\cdot}8} = 11\frac{1}{9}$ lbs.; and at 12 feet it is $\frac{60 \times 2}{12} = 10$ lbs.

Then $\frac{60 + 60 + 50 + 33\frac{1}{3} + 25 + 20 + 16\frac{2}{3} + 14\frac{2}{7} + 12\frac{1}{2} + 11\frac{1}{9} + 10}{11}$ = 28·4 lbs. as the average pressure of the steam approximately, from which must be deducted the average back pressure to get the mean effective pressure. Engineers usually ascertain the mean pressure by means of indicator diagrams, on which, after being taken, ten ordinates are drawn and measured by means of a

suitable scale, as described in Chapter XIV. of this work. The ordinates represent the pressure at the points of division throughout the stroke similar to those which we have here considered.

Question 13.—If 1 cubic inch of water at 39° F. gives 1,700 cubic inches of steam, what will be the expansion at 225° F.?

If we take a vessel of water and apply sufficient heat to it, the temperature will gradually rise till it reaches 212° F., the volume being increased from 1 at 39° F. to 1·04315 at the boiling point. At this point if the vessel be an open one the temperature of the water becomes stationary, and bubbles of invisible vapour or steam are formed at the surface exposed to the source of heat. These rise through the liquid causing ebullition and escape into the air where they soon become partially condensed and are then rendered visible. If the water be contained in a close vessel, the pressure of the steam generated gradually increases, until at last if no escape be provided, it will burst the vessel. If steam be allowed to enter an empty vessel we find that it occupies a very large space as compared with the water from which it is produced; the increase in volume being about 1,700 times. Roughly, as being a rule easily remembered we say, a cubic inch of water when converted into steam at the ordinary pressure of the atmosphere (14·7 lbs. per square inch) occupies the space of a cubic foot. Strictly, the specific volume of steam at 212° F. from water at 212° F., and at ordinary atmospheric pressure, is 1,642. If the pressure be increased the volume will be diminished in a corresponding degree, the steam produced from a cubic inch of water will only occupy about half a cubic foot when at a pressure of two atmospheres or 29·4 lbs.

The relation between the pressure and temperature of steam is of great importance, and numerous experiments have been made to determine the temperature when the pressure is known. An important property of elastic fluids was discovered by Charles, and further experimented on by Gay-Lussac, *i.e.*, that if the temperature of a given weight of any elastic fluid under constant pressure be made to vary, it will acquire augmentations of volume exactly proportional to the augmentations of temperature, and for every increase of 1° F. of temperature, there will be produced an increase of $\cdot 0020\dot{3}$ of the volume of the fluid from the temperature of 32° F.

The value of this constant is sometimes taken at ·002036.

If v be the volume of any given weight of elastic fluid under any pressure and at 32° F., the volume v_1 which it will occupy under the same pressure and at any other temperature t of F. will be $v_1 = v + v \times \cdot 0020\dot{3}(t - 32)$. This will hold good if we put the ratio of the relative volumes u and u_1 instead of the ratio of the absolute volumes v and v_1, thus $\dfrac{u}{u_1} = \dfrac{1 + \cdot 0020\dot{3}\ (t - 32)}{1 + \cdot 0020\dot{3}\,(t_1 - 32)}$.

As stated in the question the value of u_1 is 1700, of t_1 212° and of t 225° and we desire to find the value of u. Substituting these known values in the above equation we have $\dfrac{u}{1{,}700} = \dfrac{1 + \cdot 0020\dot{3}\,(225 - 32)}{1 + \cdot 0020\dot{3}\ (212 - 32)}$ $\therefore$ $\dfrac{u}{1{,}700} = 1\cdot 019326$ and $u = 1{,}700 \times 1\cdot 019326 = 1{,}733$ which is the relative volume required. That is a volume of steam at 212° F. represented by 1,700 would have a volume of 1,733 at 225° F., at the same pressure, or we may say that any volume of steam at 212° will have a volume at 225°, under the same pressure 1·019326 times greater.

But if this steam is generated in a boiler with the steam in contact with the water, the pressure as a matter of fact would not remain the same, and the volume it would occupy in the boiler instead of being greater at 225° would be less than at 212°, but the pressure would increase.

Saturated steam is not a perfect gas, and there are several formulæ for ascer-

taining the relationship subsisting between its temperature and absolute pressure. The more simple of these are only applicable, and that approximately, to certain ranges of change.

Tredgold's formula for pressures from 1 to 4 atmospheres is $p = \left(\frac{103 + t}{201{\cdot}18}\right)^6$. Applying this first to the pressure at 212° we shall find that it complies with the 14·7 lbs. already stated, thus $p = \left(\frac{103 + 212}{201{\cdot}18}\right)^6 = 14{\cdot}73$; and for the pressure at 225° we have $p = \left(\frac{103 + 225}{201{\cdot}18}\right)^6 = 18{\cdot}7816$ lbs., showing as stated an increased pressure.

From the formula to find the relative volumes when both temperature and pressure change at the same time $u = 1{,}700 \times \frac{p_1}{p} \times \frac{1 + {\cdot}0020\dot{3}(t - 32)}{1 + {\cdot}0020\dot{3}(t_1 - 32)}$ and substituting the known values in the formula $u = 1{,}700 \times \frac{14{\cdot}7}{18{\cdot}7816} \times \frac{1 + {\cdot}0020\dot{3}(225-32)}{1 + {\cdot}0020\dot{3}(212-32)}$, but as already worked out the last item in the above was found to equal 1·019326, it will render the work easier to substitute it, thus $u = 1{,}700 \times \frac{14{\cdot}7}{18{\cdot}7816} \times 1{\cdot}019326$ and therefore $u = 1{,}359$ which is the volume 1,700 cubic inches at a pressure of 14·7 lbs. and at 212° F. will occupy at a pressure of 18·7816 lbs. and at 225° F.

Question 14.—What weight would a pair of 22-inch cylinder horizontal engines with a $4\frac{1}{2}$-foot stroke and an 8-foot cylindrical drum on the first motion raise from a pit 260 yards deep with a round wire-rope, the boiler pressure being 40 lbs. per square inch? The engine works expansively, the steam being cut off at $\frac{3}{4}$ stroke.

With a boiler pressure of 40 lbs. the initial pressure of the steam in the cylinder would be, say $\frac{2}{3}$rds of this 27 lbs.

To find the pressure at the end of the stroke or at any point during expansion proceed by the following formula:—

P = Initial pressure of steam in pounds per square inch including the pressure of the atmosphere.

l = Distance travelled by the piston before steam is cut off.

L = Distance travelled by the piston when the pressure of the steam = X.

X = Pressure of steam in the cylinder including the pressure of the atmosphere, when the piston has travelled a distance L.

$$X = \frac{Pl}{L.}$$

$\therefore X = \frac{(27 + 15) \times 3}{4} = 31\frac{1}{2}$ from which deduct 15, the atmospheric pressure $= 16\frac{1}{2}$.

The average pressure throughout the stroke then is $\frac{27 + 27 + 27 + 16\frac{1}{2}}{4} = 25$ nearly. For an average pressure of 25 lbs. on the piston throughout the stroke take a boiler pressure of $25 \times \frac{3}{2} =$ nearly 38 lbs.

To find the load these engines will lift from the stated depth, and the other particulars as given. The circumference of the drum is $8 \times 3{\cdot}1416 = 25{\cdot}1328$ feet, and the area of a 22-inch cylinder is $22^2 \times {\cdot}7854 = 380{\cdot}133$. Therefore $\frac{380{\cdot}133 \times 38 \text{ lbs.} \times 108}{25{\cdot}1328 \times 12} = 5{,}172$ from which must be deducted $\frac{1}{3}$rd for

friction 5,172 — 1,724 = 3,448 lbs. and this load which the engines will lift comprises the rope and coal. The cages and tubs balance each other and need not be considered. The round wire rope used must have a safe working load then of 3,448 lbs. plus the weight of cage and tubs, say for an iron wire rope a safe working load of 57 cwt. and a $3\frac{3}{8}$-inch circumference rope will be required weighing $9\frac{1}{2}$ lbs. per fathom for the winding. In a pit 260 yards or 130 fathoms deep the total weight of such rope would be $130 \times 9\frac{1}{2} = 1,235$ lbs., and therefore the actual weight of coal these engines will lift is $3,448 - 1,235 = 2,213$ lbs. or 19 cwts. 3 qrs. 1 lb., or rather under a ton.

Question 15.—What is meant by initial, mean, and terminal pressure of the steam?

Initial is the full pressure of steam per square inch acting on the piston over a portion of its stroke previous to the closing of the steam valve. Mean pressure of steam expresses the average pressure of steam throughout the stroke, an example of how to get which is given in the answer to Question 12. The terminal pressure is that acting on the piston at the close of its stroke. Thus if steam enters the cylinder of a non-condensing engine with a 4-foot stroke at a pressure of 60 lbs. to the square inch and the steam is cut off at a quarter stoke, the absolute pressure or the pressure including that of the atmosphere is 60 lbs. + 15 lbs. = 75 lbs. By the formula in Answer 14, the terminal pressure is $\frac{75 \times 1}{4} = 18{\cdot}75$ absolute $\therefore\ 18{\cdot}75 - 15 = 3{\cdot}75$ lbs. as the terminal pressure shown by the pressure-gauge. As the engine is non-condensing it is necessary to deduct 15 the atmospheric pressure from the 18·75.

Question 16.—What provision should be made for letting the condensed water out of horizontal winding engine cylinders? and is the condensed water liable to accumulate elsewhere?

A small pipe with drain-cock should lead from either end of the cylinder and from the under side of it. There will always be a little condensation after the engine has stood some time on admitting the steam to the cylinders. Sometimes these are covered with wood and sometimes with cement, or they may be steam-jacketed as a means of retaining their heat. The steam pipes leading to the cylinders of the engine, if long, present a large cooling surface causing condensation and therefore should also have a separator and steam trap in the bend at the lowest point to allow for the escape of the condensed vapour.

Question 17.—Where would you place the brake for a winding engine and which kind do you prefer?

I prefer a well designed foot brake for small or ordinary sized engines, because a steam brake requires a good deal of fitting up, and when used comes into action very abruptly and suddenly causing some shock to the machinery, and a good foot-brake meets all the requirements, comes gently into operation, and can be gradually or firmly applied at pleasure. In powerful engines with heavy drums of large size subjected to rapid winding, the momentum acquired by the drums renders a greater brake power necessary, and where these are used, a steam brake should be adopted, in order that the engineman may have greater control over the engines. When the brake is applied to the drum, a ring is formed there which may have either one or two iron straps lined with wood or hemp rope forming the brake, and care should be taken that when the brake is "off" these straps clear the drum ring. The reason for placing the brake on the drum in preference to the fly wheel is the fact that in case of accident to any part of the

machinery the engineman could at once apply the brake on the drum, thus preventing the load from falling. A brake on the fly wheel would not have so much holding power as one on the drum ring, and in case of a broken main shaft between the drum and the fly wheel, or injury to the fly wheel, a brake on it would have no power to prevent the load from falling down the shaft.

Question 18.—What is the use of a fly wheel on a steam engine? How are its size and weight determined?

The object of the fly wheel is to render the motion of the engine uniform. If we take the case of a single cylindered horizontal engine, at the finish of the backward and forward movement of the piston in the cylinder, the piston-rod, connecting-rod and crank form one straight line, and the engine is said to be "on centre," and it is clear that any pressure on the piston when in these positions will be merely transferred to the axis of the shaft to which the crank is connected and to

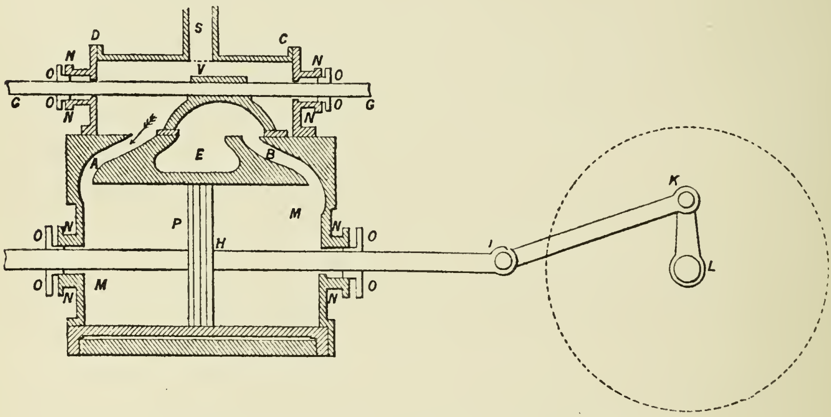


Fig. 64.—Illustrating the Action of a Winding Engine.

the bearings carrying that shaft, and therefore the pressure has no power or tendency to turn the shaft round. At these points then the crank loses all power and ceases to act. When two engines are connected to the same shaft, they are so arranged that their cranks form a right angle with each other. This prevents the engines ever being "on centre," because, when one engine is in that position, the force of the other is at its greatest, but even with a pair of engines the motion would be very irregular and uneven but for the fly wheel. When the crank is in its most advantageous position, the tendency is to increase the speed of the engine; owing, however, to the weight of the fly wheel providing a mass of matter capable of being acted upon, the fly wheel takes up a portion of the power, to be given out when the crank comes into its least effective position. Thus, the fly wheel stores up sufficient power to carry the engine over the dead points and assist in maintaining a uniform motion. The weight of the fly wheel should be so adjusted as to bear a due proportion to the power of the engine. If too heavy, it is a needless addition to the load of the engine, and if too light, the object of its use will not be gained. The practical rule is that the power stored up in it should be about equal to that produced by 6 half strokes. Thus, if the steam exert a pressure of a ton on the piston and the length of the stroke be 4 feet, the power thus generated is $6 \times 4 \times 1 = 24$ tons. The weight and velocity of the wheel should therefore be so arranged that its momentum is about

equal to this. If the weight of the rim then be 1 ton its velocity should be that which would be acquired by a body falling 24 feet; if it weigh $1\frac{1}{2}$ tons it should be that acquired in falling 16 feet, and so on in proportion.

Question 19.—Explain the working of the winding engine; show by a sketch its chief parts and give their names.

Fig. 64 is the sketch.
S is the steam pipe leading from the boilers.
C D is the steam or valve chest.
V is the slide valve.
G G is the valve or slide rod.
A & B are the steam ports.
E is the exhaust port.
P is the piston.
H I is the piston rod.
I K is the connecting rod.
K L is the crank.
M is the cylinder.
N N are the stuffing boxes.
O O are the glands.

The steam enters the valve chest D C through the steam pipe S. It then passes into one of the steam ports A or B, but if one is open the other is closed and the steam may be made to enter either first at the will of the engineman who, by means of reversing gear, can move the slide valve V and so close either one of the steam ports and at the same time open the other.

Assuming it to have entered on the side of the piston P, shown by an arrow on the sketch, *i.e.*, through the steam port A, the piston will make a forward movement to its full extent, but whilst doing this a movement is conveyed in the opposite direction by means of the slide rod G G to the valve V, and this movement causes the valve to close over the steam port A, and at the same time it has cleared the steam port B, and placed the valve so that the steam may enter at B to drive the piston back, and also convey the exhaust steam which has just finished doing its duty through the exhaust port E leading to the condenser or the atmosphere. This backward and forward or reciprocating movement of the piston is conveyed, by means of the piston rod and connecting rod, to the crank K L which turns the main shaft on which is placed the drum, and the drum thus revolves.

Question 20.—What causes the motion spoken of in the slide rod, and what is the object of placing stuffing boxes and glands for it and for the piston rod to work in?

Motion is conveyed to the slide rod by means of two eccentrics placed on the main shaft, working in eccentric straps, and rods connect these by means of links to the slide rod, the two eccentrics being necessary for the reversing of the engine.

The object of stuffing boxes and glands is to allow the rods to move up and down without excessive friction, and yet at the same time prevent any leakage of the steam.

A well-lubricated packing is placed in the stuffing box, and a gland of brass is screwed down to keep this in place. Brass bearings cause less friction for iron to work in than iron.

Question 21.—Of what are the cylinders and pistons made, and in the continual motion of the piston in the cylinder, what provision is made for wear to the part exposed to the constant friction?

The cylinder is made of cast iron and is of considerable thickness. Its interior surface is bored with great care, so that it is of uniform diameter throughout and perfectly cylindrical. When the uniformity of diameter is destroyed through wear, the cylinder is re-bored. Covers are bolted on each end and the joints packed, so as to be perfectly steam-tight. Pistons are also made of cast iron, but sometimes they are made of brass. It is of the utmost importance that the piston be in perfect contact at all parts with the cylinder, so that no steam may pass by, and yet in that contact the friction must not be needlessly increased by too strong a pressure against the sides. For this purpose different kinds of packing are used. Formerly it was the custom to turn a deep groove round the edge of the piston disc, and into this groove was inserted well-lubricated hemp packing. The piston was made in pieces, and the top disc was attached to the rest by screws. These screws on being tightened forced the packing

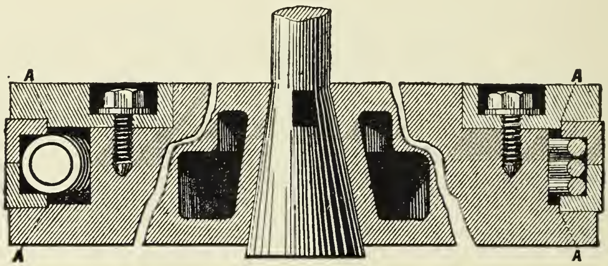


Fig. 65.—Lancaster P.ston Block.

against the sides of the cylinder, thus preventing the steam from passing and preventing undue wear of the piston or cylinder. From time to time, as required, the cylinder cover would be removed, the piston withdrawn from the cylinder, and the packing renewed. The trouble and inconvenience resulting from this method are now, however, avoided by using metallic pistons of different construction. By using these no packing is required. For the metallic pistons the grooves formed are rectangular in form, and instead of the hemp, two or more packing rings are used which, at first, were made of brass or steel. These packing rings were flat, and had the same external diameter as the piston; they were made in several segments, the ends being tongued and grooved to keep them in position; and the joints were so arranged in each ring as to be intermediate to those of the other. These segments were constantly acted on by strong steel springs placed in the piston, the effect of which was to press them against the interior of the cylinder, and as they became gradually worn they were pressed out to exactly fit it. There were four or five springs, all tightened by screws placed for the purpose, and they were so adjusted as to keep the packing rings in contact with the interior of the cylinder without causing undue friction. The packing rings are now nearly always made of cast-iron. After turning they are left rather larger than the bore of cylinder. They are then cut across, so as to allow of compression sufficient for entering the cylinder with the piston. Where the rings are cut across they are connected by a thin plate, and the joints in the two rings are placed as far apart as possible and opposite each other, so as to ensure steam-tightness. Proper oil receptacles are placed on the cylinders, and these are kept continually replenished with good lubricating oil which passes

into the interior, and very little wear then results to the metallic piston; but when necessary they can be easily repaired.

It is usual to screw the piston rod into the piston. Formerly, where no tail rod was used, the piston rod was passed through the piston and secured on the other side by a nut. After working some time the nut would wear loose and so give trouble. The object of having a tail rod on a horizontal winding-engine is to steady and guide the piston in its motion.

There are very many patent forms of pistons, in each of which is some novelty for which the inventor claims superiority in design and construction.

Messrs. Lancaster & Tonge, Engineers, Pendleton, near Manchester, make a patent piston block, which is shown at Fig. 65. It is designed to keep the body of the block from the cylinder and the rings from being driven inwards, thus obviating the uneven wearing of the cylinder by the block bearing on it. The

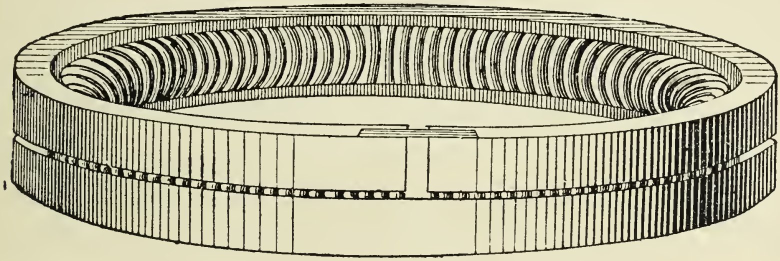


Fig. 66.

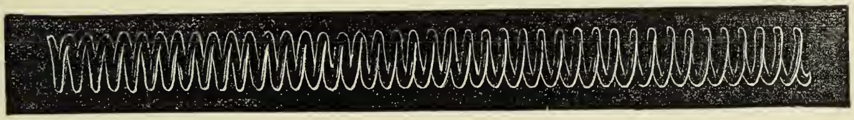


Fig. 67.

LANCASTER PISTON RINGS AND SPIRAL SPRING.

grooves A A are turned so that the rings rest on them, but being free to expand, keep the piston perfectly steam-tight.

Figs. 66 and 67 show the piston rings and one arrangement of springs, while Figs. 68 and 69 also show the piston rings and another arrangement of springs for the Lancaster piston.

These two arrangements of springs are also shown on Fig. 65 on opposite sides of the piston. A straight spiral spring, Fig. 67, is bent into a circle, Fig. 66, and then has two actions, *first*, the continuous effort of the straight spiral spring when forced into the circular rings, to recover that form; and *second*, the straight spiral spring being diametrically compressed when forced into the rings, makes a continuous effort to recover its original diameter. The lateral pressure is thus obtained by forcing the rings against the sides of the cylinder, and the vertical pressure by the rings being grooved to the circle of the spring, thus forcing the rings against the block and junk ring. It is self-adjusting, perfectly steam-tight, with a minimum of friction.

Figs. 68 and 69 show the "Lancaster" serpent coil, which is a round section of tempered steel, and has therefore many advantages over those made from a flat section. The round coil against a flat surface cannot bind, but causes a revolving tendency in the packing rings. There is no difficulty in putting in; the rings being slightly rounded, the round coil slips in with the greatest ease.

Question 22.—Describe Joy's valve gear.

Joy's gear is an arrangement for working the slide valves of steam engines and it is claimed for it that it is a more perfect appliance than the usual link motion worked by eccentrics on the main shaft, and can be adopted wherever the link gear is applied. In Joy's gear the necessary motion for the slide valve is obtained from the connecting rod.

The following sketch, Fig. 70, and description are taken from Percy's *Mechanical Engineering of Collieries.*

In the connecting rod from a point A, preferably about the middle, motion is imparted to a vibrating link B, constrained at its lower end to move vertically by the radius rod C. From a point D, on this vibrating link, horizontal motion is communicated to the lower end of the lever E from the upper end of which lever the motion is transmitted to the valve spindle by the link G. The centre or fulcrum, F, of the lever, E, partakes also of the vertical movement of the connecting rod,

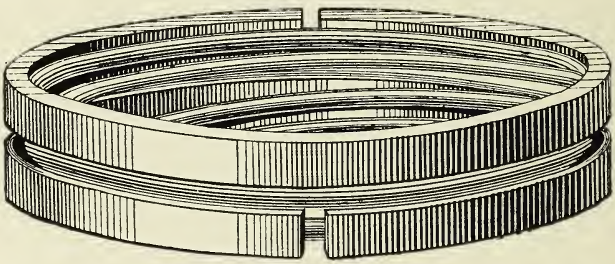


Fig. 68.

Fig. 69.

Lancaster Piston Rings and Serpent Coil Spring.

to an equal extent to the amount of its vibration at the point, A; the centre, F, is for this purpose carried vertically in a slot, J, which is carried to a radius equal to the length of the link, G, connecting the lever, E, to the valve spindle. The slot itself is formed in a disc or sheave, K, which is concentric with the centre, F, of the lever, E, at the moment when that lever is in the position given by the piston being at either end of the cylinder. This disc is capable of being partially rotated on its centre, so as to incline the slot over to either side of the vertical, by means of the worm and hand wheel, M, thereby causing the curved path traversed by the centre, F, of the lever, E, to cross the vertical centre line, and diverge from it on either side at will. The forward or backward motion of the engine is governed by giving the slot this inclined position on one or other side of the vertical centre line; and the amount of expansion depends on the amount of the inclination, the exactly central or vertical position being "mid gear." In that position steam is admitted at each end of the stroke to the amount only of the lead; and this is done exactly equally on each side of the centre line, the amount of lead being constant for forward and backward motion, and for all degrees of expansion. Thus, when the crank is set at the end of the stroke either way, the centre, F, of the valve lever coincides with the centre of the slot, and therefore the slot may be moved over from forward to backward gear without

affecting the valve at all. It will be seen at a glance, that, if the lower end, D, of the lever, E, were attached directly to the point, A, on the connecting rod, there would be imparted to the centre, F, of that lever an unequal vibration above and below the centre of the disc, K. The extent of inequality would be twice the versed sine of the arc described by the lower end, D, of the lever, E; and this would give an unequal port and unequal cut-off for the two ends of the stroke. But this error is corrected by attaching the lower end, D, of the lever, E, to the vibrating link, B; for while the point, A, on the connecting rod is performing a nearly true ellipse, the point, D, in the vibrating link, B, is moving in a figure like an ellipse bulged out at one side, and this irregularity is so set as to be equal in amount to the versed sine of the arc described by the lower end of the lever E, thus correcting the above error, and giving an equal travel to the centre, F, of the lever above and below the centre of the slot. At the same time, the error introduced by the movement of the end of the valve link, G, is corrected by curving the slot, J, to a radius equal to the length of G.

These two errors may, however, be set against each other, and a compromise may be made by attaching the end of the lever, E, direct to the connecting rod

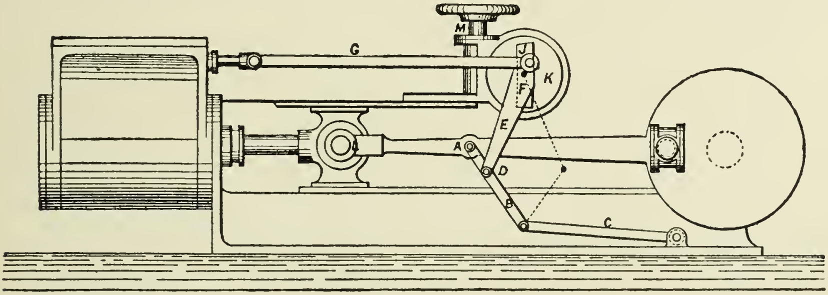


Fig. 70.—Joy's Valve Gear.

at A, and allowing the centre, F, to slide in a straight slot. By a just balancing of the errors so produced, and by making the centre, F, of the lever, E, and the centre of the disc, K, to coincide at varying points in the travel of the former, a fair motion may be got for the forward gear of an overhead marine engine, giving a longer cut-off for the up stroke than for the down stroke. This is, of course, at the sacrifice of the backward gear, in which the reverse is the case, and the various degrees of exhaustion are between the two extreme conditions.

Referring again to the equalising of the traverse of the centre, F, of the lever, E, in the slot, J, the unequal traverse may be either under corrected or over corrected by shifting the point, D, in the vibrating link, B, nearer to or further from A; by this means a later point of cut-off may be given to either end of the cylinder at will, and the engine may thus have more steam admitted to one side of the piston than to the other if required. The same thing may be done for the lead. By altering the position of the crank, for which the lever centre, F, coincides with the centre of the slot, J, an increased or diminished lead may be given. The central positions and exact corrections are, however, in all cases standard and equal.

Question 23.—What is the object of a winding indicator, and where is it usually placed?

The object of any winding indicator is to show the position of the cages in their ascent and descent in the shaft, and it should be placed well within the view of the engineman in the engine-house whilst at his duty there. The indicator

receives its motion from the crank shaft, to which, in the ordinary form of indicator, one end of a small chain is attached and round which it is wound. The other end is carried, by means of pulleys, overhead to a suitable place in the wall of the engine-house, and has there attached to it a well-defined pointer, which travels in a groove formed vertically in a frame resting against the wall. When the cages are at certain levels in the shaft, it is shown to the engineman by the travelling pointer reaching certain marks formed in the indicator, in addition to which it is made to ring a bell each time the ascending cage approaches the surface, thereby giving warning to the engineman to close the steam valve.

Another form of indicator, worked by gearing off the crank shaft, consists of a circular dial face with an index hand moving round it, which indicates the position of the cages by well-defined marks on the dial face.

Question 24.—Describe any system or systems of winding coal up shafts in which the use of the drum on the engine is dispensed with.

The use of the drum is dispensed with in Craven's Improved Winding Gear for Mines, and also in the Kœpe system of winding. The following description of the former method appeared in the *Colliery Guardian* of June 9th, 1882:—

"Important improvements have lately been introduced by Mr. John Craven, of Wakefield, in the form and arrangement of winding gear for mines, for the invention of which letters patent have been granted. The improvements consist mainly in obviating the necessity for coiling ropes round the drums usually employed, and so removing the danger and expense arising from the great wear and frequent injury of the ropes by one coil chafing against the other. In order to effect these objects, the inventor employs a single winding rope, an upper set of grooved headgear pulleys, and a lower set of grooved winding pulleys, each consisting of two pulleys, and an intermediate grooved pulley between the two sets. The rope is attached at one end to one of the cages, passes over one of the headgear pulleys, under one of the winding pulleys (to which the motive power is applied), and back over the intermediate pulley, and then under the other winding pulley, and thence over the other headgear to the other cage, to which the end of the rope is attached. This arrangement is designed to give greater durability to the rope, and to obviate all tendency to slipping of the rope, as in proportion as the weight of the load is increased the adhesion of the rope is augmented. The bearings of the intermediate pulley may be carried in a movable frame, either inclined or otherwise, so as to admit of the pulley being adjusted as required, in order to maintain the rope taut.

"Fig. 71 represents in elevation and Fig. 72 in plan a winding-gear constructed and arranged after the method above described. A set of two-grooved headgear pulleys is mounted in bearings in the headgear or frame-work, and another set of two-grooved winding pulleys is keyed on the crank shaft of the engines in the engine-house. The headgear pulleys are preferably set at an inclination inwards towards the winding pulleys in the engine-house, as shown in the plan. The intermediate grooved pulley is mounted in bearings carried by the framework. The single winding rope is attached at one end to one of the two cages and passes over one of the headgear pulleys, thence under one of the winding pulleys in the engine-house, and then back and over the intermediate pulley, and then under the other winding pulley in the engine-house, and to and over the other headgear pulley to the other cage, to which the end of the rope is attached. The winding engine is represented in the engraving, and its power is applied to the crank shaft of the engines, on which the winding pulleys are mounted, so as to drive the pulleys in the one or the other direction for raising the one cage and lowering the other by the one rope. The bearings of the intermediate pulley are in blocks which are capable of sliding upon guides carried by the framework. To

these blocks are attached the rods represented in the elevation, the other ends of which are screwed and pass through lugs, and are provided with screw nuts. By screwing up or slackening these nuts the bearings can be moved in one or the other direction to maintain the rope taut, or to slacken or tighten it as required. The following specific advantages are claimed for the invention:—No chafing of rope as in the ordinary system of drum, so that the ropes last longer; reduction

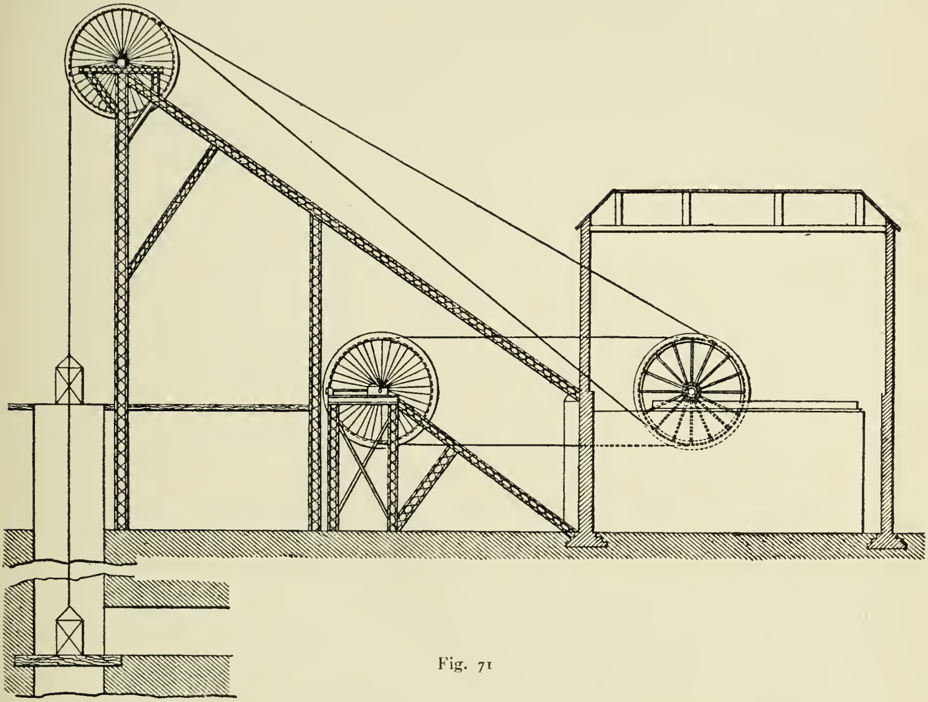


Fig. 71

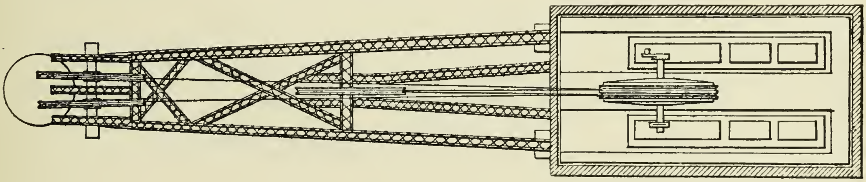


Fig. 72.

Craven's Winding Gear.

of work for the engine to do in starting; reduction of strain upon the engine, &c., in stopping; speed, instead of being obtained by a large diameter of drum, is got from the engine running quickly; a smaller engine is required than with ordinary gear, owing to the comparative lightness of the winding pulley; the winding pulleys have only one groove each, and are of very small weight comparatively; saving in first cost, the engine-house being much narrower, and only one rope required instead of two; great adhesion, no slip occurring between the rope and the pulleys."

Mr. Percy, in his *Mechanical Engineering of Collieries*, describes the Kœpe system as follows:—

"The Kœpe system of colliery winding dispenses altogether with winding drums and substitutes a pulley. One winding rope answers for, and is attached to both cages instead of having a separate rope for each. This rope having a cage at each end simply passes about half round an ordinarily constructed **V** pulley on the crank shaft. The balance rope under the cages is used in connection with the Kœpe system. The advantages claimed for the arrangement are manifold. First, massive winding drums are abolished, thus avoiding the enormous weight to start and stop each winding. Second, the pair of engines can be brought closer together, thus making the crank shaft shorter. Third, a smaller engine-house is required. Fourth, only one rope is actually used for winding. Fifth, the rope always coils round exactly the same diameter. Sixth, the rope always works in the same line. Seventh, the load is exactly uniform throughout the winding. Eighth, a smaller pair of engines are equal to the work. Objections have been taken to the arrangement that the rope is liable to slip upon the drum-pulley; if the rope breaks the two cages fall down the pit; and the difficulty in re-capping. However, the Kœpe system has been fairly tried at the Bestwood Collieries and has been successful. There are two pits exactly the same depth and raising the same load in equal times, the steam for the engines coming from the same range of boilers. The Kœpe engines have 30-inch cylinders and $5\frac{1}{2}$-foot stroke. The non-Kœpe engines have 36-inch cylinders and 6-foot stroke. Such a result is certainly encouraging for the advocates of the Kœpe system of colliery winding."

In the appendix to the same work, Mr. Percy, referring to the same subject, writes:—

"The Kœpe system as arranged at Bestwood is more elaborate than has been described in Chapter IV.

"True, there is only one winding rope, but there are two lighter or safety ropes also attached to both cages, and the object of these is that should the main rope break, the cages will not run down the pit. The manner of their operation is somewhat curious. The ends are attached to the respective cages, and the ropes pass over two pulleys in the headgear. The diameter of these pulleys is the distance from centre to centre of cages. So long as the main rope does not break, these safety ropes simply move about, but when the main rope breaks, the safety ropes have the weight thrown upon them, and pressing down upon their pulleys are brought to a stand, and prevent either cage from running back. This arrangement necessitates, in addition to the main rope, two safety ropes, and a balance rope under the cages equal in weight to the other three. It is really no part of the Kœpe system, introduces complication, and is not necessary. The Kœpe system proper consists as described, of one winding rope, one balance rope and one drum-pulley."

Neither Mr. Craven's nor the Kœpe system appears to have become at all popular.

Question 25.—State any rules you know for finding the nominal horse-powers of engines.

Molesworth gives the following:—

"Nominal" horse-power means very little; the term is arbitrary and varying. The actual or indicated horse-power varying in stationary engines from $2\frac{1}{2}$ to 3 times the nominal horse-power, and in marine engines it is sometimes 6 or 7 times the nominal horse-power. It is now becoming obsolete for marine engines

V = mean velocity of piston in feet per minute.
D = diameter of cylinder in inches.
S = stroke of engine in feet.
H = horse-power of engine.

For high pressure engines.

$$H = \frac{D^2 \sqrt[3]{S}}{15{\cdot}6}$$

$$D = \frac{\sqrt{15{\cdot}6\, H}}{\sqrt[3]{S}}$$

$$V = 128 \sqrt[3]{S}$$

For condensing engines.

$$H = \frac{D^2 \sqrt[3]{S}}{47}$$

$$D = \frac{\sqrt{47\, H}}{\sqrt[3]{S}}$$

$$V = 128 \sqrt[3]{S}$$

Mr. Greenwell gives the following :—

For high pressure engines.

$$H = \frac{D^2}{13{\cdot}6}$$

For condensing engines.

$$H = \frac{D^2}{30}$$

CHAPTER V.

SURFACE ARRANGEMENTS *(Continued)*.

STEAM BOILERS AND THEIR FITTINGS.

Ordinary Forms of Colliery Boilers, "Egg-Ended," Cornish, and Lancashire—General Construction and Flue Arrangements—Galloway Tubes for Cornish and Lancashire Boilers—Details of Construction—Riveting, Punching, and Drilling—Caulking—Welded Shell Joints—Attachment of Flat Ends—Expansion Joints for Internal Tubes—Relative Strengths of Different Riveted Joints—Diagonal Seams—Complete Shell Rings—Means of Strengthening Apertures cut in the Shell—Seating a Lancashire Boiler—Faulty Methods of Seating—Seating Blocks and Crown Tiles—Means of Preventing Radiation of Heat—Position on the surface in which to place Boilers—Boiler Fittings—Mechanical Stokers—Hydraulic Test—Steam-pipe Connection—Steam-pipe Expansion Joints—Heating the Feed-water before it enters the Boilers—Feed-pumps and Injectors—Chimneys and Chimney Flues—Galloway Breeches-Flued Boilers—Babcock and Wilcox Water-tube Boilers—Vertical Boilers—Safeguards against Explosions—Grooving, &c.—Necessity for Care in Tending Boilers—Water Impurities—Analysing and Purifying Feed-water by the Addition of Chemicals—The Hotchkiss Boiler-cleaner—Seale's Patent Water Purifier—Periodical Examination of Boilers by Experts—Causes of Explosion—Dangerous Practices when Cleaning Boilers—Warming Surface Buildings by Steam—Rules Relating to Boilers—Separators and Steam-traps—Feed-water Heaters and Economisers—Warning Whistles, &c.

Boilers are necessary for the generation of steam to supply the engines with their motive power. They have been made of various forms at different times, but those now mostly used for colliery purposes are the common cylindrical boiler, the Cornish, and the Lancashire. The efficiency of boilers is expressed by their evaporative power of water per lb. of coal consumed on the fire-grate. Common boilers evaporate about 7 or 8 lbs. of water per lb. of coal consumed, and Cornish and Lancashire boilers from 10 to 12 lbs.

The plain or Egg-ended Boiler, shown at Fig. 73, is fired externally, the fire-grate being situated underneath the boiler, but not shown on the sketch. Boilers of this type are made in lengths varying from 20 to 35 feet, 30 feet being a common length. There is little or no gain by extending the length beyond 35 feet. The construction of this boiler is very simple; it does not require any stays whatever, either at the hemispherical ends or elsewhere. The disadvantages attending its use arise from the fact that it is a large coal consumer, and that all sediment, collected in the bottom of the boiler, is immediately over the greatest heat, and there is, consequently, a great risk of burned plates. Again, owing to its small amount of heating surface, steam cannot be so rapidly generated in it, nor obtained from it, at the high pressure so frequently required at collieries. Formerly, the products of combustion were conveyed round the boiler by what was termed a "wheel-flue." Having passed under the boiler to the end, the products of combustion entered a side flue, thence traversing along one side of the boiler, across the front end, back along the other side, continuing on to the chimney. The present practice is to dispense with this, and the boilers have what are known as "flash-flues," that is, the products of combustion pass under the boilers, and direct to the chimney.

A Cornish boiler has two flat ends and one internal flue passing from end to

end. The object of the internal flue is to give a greater heating surface than that of the egg-ended boiler.

Fig. 74 shows a sketch of this boiler.

The products of combustion pass from the fire-grate through the internal tube

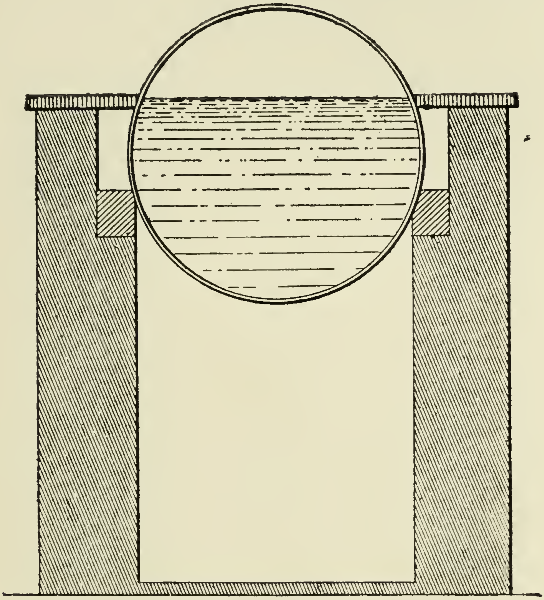


Fig. 73.—Common Cylindrical Boiler.

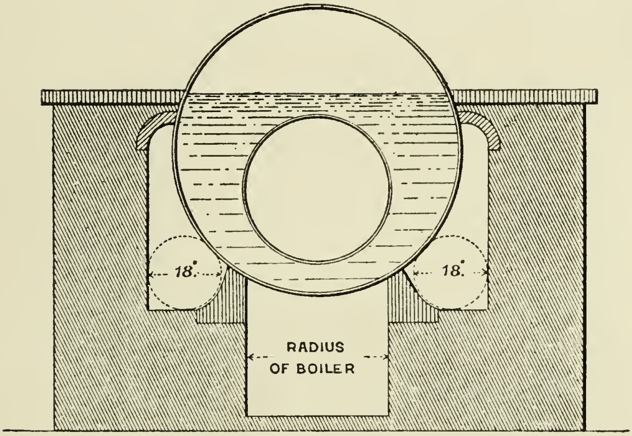


Fig. 74.—Cornish Boiler.

to the back end of the boiler, then, dividing, they return to the front end along the two side-flues. Here they pass down to the bottom flue, and, re-uniting, pass underneath the boiler to the chimney.

Where the flues are traversed thus, the gases are reduced in temperature before coming in contact with the bottom of the boiler, where all sediment collects, and all danger of burned plates on the under side of the boiler is avoided. Where

the water used in the boilers is pure, or with boilers of such a length as to ensure the gases being considerably cooled before leaving the furnace flue, it is usual for the products of combustion to be brought first along the flue under the boiler to the fire end, where they divide and pass upwards into the two side flues, which they traverse to the end of the boilers, and thence to the chimney.

It has been estimated that the temperature of the gases escaping from boilers of the Cornish and Lancashire type having a moderate draught is about 600° F.

The egg-ended and Cornish boilers are usually made 6 feet in diameter.

The Lancashire boiler, like the Cornish, has two flat ends, but it has two internal flues running from end to end, and is usually from 7 feet to 8 feet in diameter.

The Cornish and Lancashire are internally fired, a furnace being placed at the one end of the internal flue of the Cornish, and two furnaces at the one end in the two flues of the Lancashire.

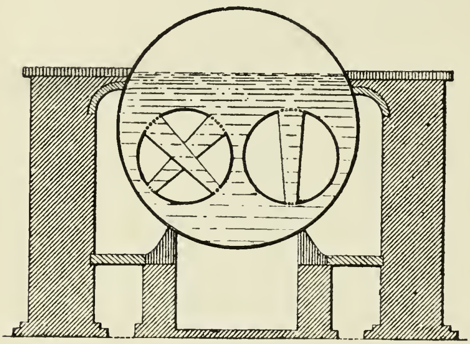


Fig. 75.—Lancashire Boiler with Galloway Tubes.

Fig. 75 is a sketch of a Lancashire boiler fitted with Galloway tubes.

The Cornish Boiler is suitable for small powers. If boilers of great power were made of the Cornish type, an excessively large furnace flue would be required, in order to give sufficient grate surface. The length of grate is regulated by the reach of the fireman, and in practice is made from 5 to 7 feet. A flue of large diameter is weak to resist collapse, unless very thick plates are used in its construction, and thick plates are undesirable in steam boilers.

The Lancashire Boiler is designed to meet the requirements of large power, the two flues of moderate size serving the same purpose as one large one. The arrangement of the external flues is the same as that described for the Cornish boiler.

In both the Cornish and Lancashire boilers the effective heating surface is increased, and a better circulation of water in the boilers promoted by the use of "Galloway" tubes. A further advantage of the "Galloway" tubes is the increased strength given to the flue in which they are placed. They are conical in shape, and pass through the central flues beyond the fire-bridge, some being placed vertically and others diagonally, those placed diagonally being at right angles to each other.

In a line of tubes a vertical, right-hand diagonal, and left-hand diagonal, are placed in succession. The conical tubes are about 5 inches larger in diameter at the higher than at the lower end. Galloway tubes may have Gamgee spouting cowls applied to them. A cowl consists of a dome extending from the top of the tubes to about four inches above the water-line. The dome contains an inverted cone, the object of which is to cause the ascending hot currents of water to pass from the top of the Galloway tube into a gradually contracted space. The reduced area increases their velocity and causes them to be ejected into the steam space above the water-line. The colder water falls to the bottom of the boiler, and so the whole body of water is kept in more active circulation.

In constructing these boilers, iron or mild steel plates are used, the joints in the shells of which are riveted together by either a single or double row of rivets.

The holes formed in the plates for the rivets are either drilled or punched, and the rivets may be either oval, or, what is much more common, circular in form,

and the riveting may be done by hand or mechanical power. The plates should all be of good quality, to stand the various processes of flanging, welding, punching, &c., to which they are subjected. The plates forming the furnace flues are more severely taxed by variations of temperature than any others in the boiler, those of the furnace-crown especially being subjected alternately to the fierce hot flames from the fire and the currents of cold air which rush into the furnace every time the firing door is opened.

Steel is unquestionably a better material for the construction of boiler than iron, but great care must be paid to its special properties, and plates of a mild nature, possessing moderately high tensile strength, but great ductility should always be used.

Boiler makers test the plates used for boiler making in many ways. One test for ductility is to bend back the flange of a plate when cold. Another test for steel plates is to cut strips, which are heated red hot, then plunged into cold

Fig. 76.

Fig. 77.

Fig. 78.

Fig. 79.

BOILER-PLATE JOINTS.

water, after which they are bent cold to a certain defined radius. The ductility is fully proved if the strip shows no sign of fracture.

Thinner plates of steel may be used than would be necessary with iron plates in boilers worked at a given pressure.

The joints of the flues are formed either by riveting or welding.

Riveted joints are either lap-joints or butt-joints.

In the ordinary lap-joint the edge of one plate projects, or laps over the edge of the next plate as shown in Fig. 76. Sometimes the plates are slightly thickened at the portion forming the joint, as shown in Fig. 77.

In the butt-joint the two plates are placed level and uniform, edge to edge with each other, and the connection made by either a single cover-plate, as shown at Fig. 78, or by a double cover-plate, shown at Fig. 79. Rivets are then driven through the boiler and cover-plates.

Where lap-joints are made the plates are cut to overlap one another slightly, and then bent to the proper curvature.

All joints in the shell of a boiler are single, double, or triple riveted, but triple rivets are only used in the seams of marine boilers of large diameter, and working at high pressure.

The simplest form of joint is a single riveted lap-joint, but it is also the least efficient. The rivets are placed about two inches apart centre to centre, and are about $\frac{5}{8}$ths of an inch in diameter.

Double riveting is done in one of two ways. Where the rivets of one row are placed opposite to the spaces between the rivets of the other row, it is termed *zig-*

zag riveting as shown in Fig. 80. Where the two rows of rivets are placed opposite each other, it is called *chain* riveting, as shown in Fig. 81. Zig-zag riveting requires less lap than chain riveting, besides making a tighter joint, but the plates are not so strong. The chain riveted makes the stronger joint, and is coming more into use.

There are some advantages in punching the holes in the plates, and some in drilling them. The strongest argument against punching plates lies in the fact that the plates are punched when flat, and afterwards bent to shape, whereas the drilling is done after the plates have been bent.

A plate with punched holes receives damage along the row of holes in bending. To some extent, also, punching injures the texture of the metal immediately surrounding the hole. Again, where the punching is carelessly performed the holes in the plates do not correspond. What is called *drifting* is then resorted

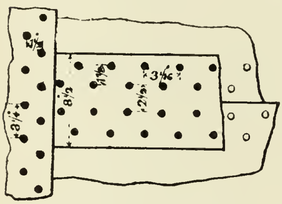


Fig. 80.—Zig-zag Riveting.

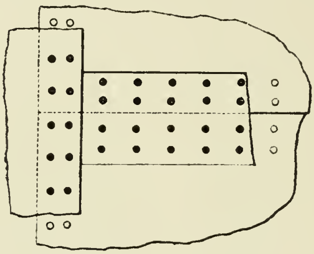


Fig. 81.—Chain Riveting.

Fig. 82.—Punched Holes.

to. It consists of bringing the two plates into good alignment for receiving the rivets by either a pointed or barrelled drift. Where the contiguous holes of two plates are so much out of correspondence as to be nearly blind the pointed drift is used.

The practice of drifting is most objectionable, especially with the pointed drift, as the plates are injured by it. Where the holes do not quite coincide they should be drilled true. It is quite true that the plates when drilled separately present the same difficulty with respect to a want of agreement between the rows of holes.

Drilling machines are now in use whereby the plates are drilled when fixed in position, thus ensuring an absolute coincidence of the holes in the different plates.

The holes formed by drilling are of a uniform size throughout the plates, but punched holes are slightly tapered as shown in Fig. 82. When the plates are placed together, the small ends of the holes are placed inside the joint, and the larger ends outside. There is in this a decided advantage in the punched holes, as when the rivets are driven in they hold the plates more firmly, and make a tighter joint than with the parallel holes of drilled plates.

The edges of drilled holes are sharp, and exercise a cutting action on the rivet; if slightly counter-sunk the strength of the rivets is increased, but this adds to the expense. No cutting action takes place at the outer edge of a punched hole.

From experiment it seems well established that where the plates are punched the rivets are stronger, but the plates are weakened to a greater degree; and altogether joints made with drilled holes are rather stronger than joints made with punched holes.

The rivets should be of the best Lowmoor iron or mild steel, and are heated in a common portable hearth before being hammered down. Greater care is required with steel rivets than with iron, as steel is a material which suffers even

greater injury than iron from being over-heated. As the rivets cool they contract and draw the plates closer together. Formerly, all the joints were riveted by hand, but now wherever a machine can be applied it is used to do the riveting. Besides doing the work more quickly, good machine riveting is superior in strength to hand riveting. The hydraulic riveting machine is mostly used for the purpose. In machine riveting the pressure on the whole body of the rivet is more gradual than that resulting from the sharp, sudden blows of a hammer in hand riveting. This gradual pressure, resulting from powerful squeezes, forces the rivet into the hole, making its filling a matter of certainty before forming a head at all, and the joint is, therefore, more secure. The act of riveting with a mechanical riveter is momentary, and the point of the rivet is not rendered brittle by being repeatedly hammered when at a low heat or cold. Care should be taken to have the plates drawn closely together before riveting, or the compression of the body of the rivet into the hole may cause a slight shoulder to be formed between the plates, which will prevent the closing of the joint.

When the riveting of the boiler is completed, the joints should all be carefully caulked, so that they may be absolutely steam and water tight.

The usual practice is what is called split caulking. Fig. 83 shows this method as applied to a lap-joint, and Fig. 84 as applied to a butt-joint.

By means of a tool something like a chisel a score or split is cut as shown in the figures. This brings the extreme edge of the lap into close contact for about $\frac{1}{8}$th of an inch, but at the same time is objectionable, as in the case of lap-joints it is liable to open the plates between the extreme edge and the point where they are held tightly together by the rivets. For this reason, many makers have now largely given up split caulking.

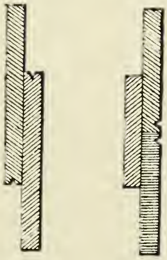


Fig. 83. Fig. 84.

SPLIT CAULKING.

The best practice consists in planing the edges with a slight bevel, and then by means of a proper caulking tool the surfaces are driven into close contact without injuring the plates.

A boiler shell consists of rings formed of plates from three to four feet six inches wide, rolled with the grain running circumferentially. Each ring is usually composed of two or three plates. Steel plates are now rolled large enough to admit of one plate forming an entire ring, so that there is only one longitudinal seam in a boiler made of such plates.

Within the last few years boilers have been made with welded joints in the shells. If the soundness of these joints were assured, a boiler made of complete rings would possess advantages over one built in the ordinary manner, in having fewer joints, which, besides being the weakest parts of a boiler, are the places where leakage most frequently occurs, and external corrosion arising therefrom. The soundness of welded joints is, however, still uncertain, and for this reason boilers built with these ring plates have not become popular.

The plates in the rings are connected to each other by lap or butt joints, as are also the rings to each other.

The circular seams form a continuous line round the boiler, but the horizontal or longitudinal seams are not continuous, the joint in each ring being intermediate to joints in the adjoining ring.

The flat end plates are each in one piece, the portion to receive the internal flues being bored out of each plate, and are connected to the shell in different ways.

Fig. 85 shows the usual method of attaching the front plate to the shell and to the internal tube, and Fig. 86 the method of joining the back plate to the outer shell and internal tube. In Fig. 85 a ring of angle iron is placed outside the

shell, and riveted to the shell and to the front plate. The internal tube is usually similarly dealt with at both the front and back ends, having a ring of angle iron placed outside it at either end, the angle iron being riveted to the tube and to the end plate as shown in Figs. 85 and 86.

Occasionally both the front and back plates are attached to the shell by inside angle iron, but usually the back end plate is flanged and then riveted to the shell plates by an ordinary lap joint as shown in Fig. 86.

Sometimes the internal flue is attached to the end plates by flanging the end plates inwards or outwards.

The longitudinal seams of internal boiler tubes are either welded or butt jointed. The reason why no lap joints are made in the internal flue is that any departure from a truly circular section gives less resistance to collapse. The cylindrical shell of a lap-jointed boiler is not perfect in form, but the *internal* pressure to which it is subjected, has a tendency to rectify the defect and to bring

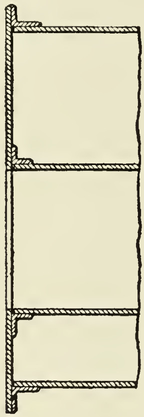


Fig. 85.—Attachment of Front-end Plate.

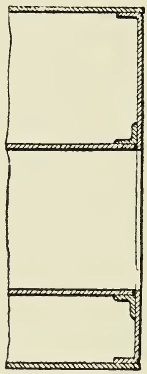


Fig. 86.—Attachment of Back-end Plate.

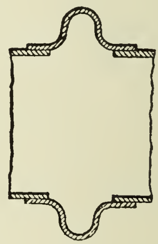


Fig. 87.—Bowling Hoop Expansion Joint.

the shell to the form of an exact cylinder. The effect of *external* pressure on an imperfectly cylindrical tube, however, increases the defect and causes a greater departure from the true circular section. By welding the longitudinal seams or by butt-jointing them, the truly cylindrical form is approached as nearly as practice allows.

In addition the internal tubes require strengthening and also to have some provision for expansion and contraction, as they are subjected to great heat and sudden admissions of cold air. It is customary now to secure the different rings forming the flue to each other by an expansion joint. At first a ring of T iron was used for strengthening the tubes. It was riveted round the joints of each ring of plates, and although found to give sufficient strength it held the flue too rigidly and did not allow free expansion and contraction to take place.

Fig. 87 shows the Expansion or Bowling Hoop, which has been much used for flue joints. It is weldless and can be made in iron or steel. It is as strong as the T iron ring with the advantage of allowing free expansion of the tube. The objection to it is that it exposes two rows of rivets and a double thickness of plates to the intense heat of the furnace, and these are therefore liable to be burned.

Another form of expansion joint is known as Adamson's Flanged Seam, and is shown at Fig. 88.

In it the ends of the flue plates are flanged and connected by means of rivets with a ring placed between. The object of the ring is to give a caulking edge on

each side of the lap. This joint is very elastic and allows free expansion and contraction to take place.

By its use no double thicknesses of plate and no rivets are exposed to the action of the fire. All plates which require flanging must, however, be of excellent quality and even then if not skilfully done, the joint gives a considerable amount of trouble.

Fig. 89 shows another method of strengthening flues and of allowing for their expansion and contraction; viz. Paxman's Flue Joint. It consists of welded rings of iron or steel, which are rolled out accurately in a machine to the shape shown on sketch, the connection being made by a simple lap joint. This joint allows for expansion. The rivet heads and double thicknesses of plate although not removed from the action of the fire are out of immediate contact with it.

Foxe's corrugated furnace flues are stronger than the plain flue fitted with any of the strengthening rings mentioned, and yet their shape allows every facility for expansion, whilst giving greater heating surface than the ordinary flue. An

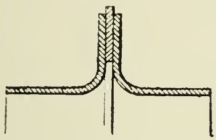


Fig. 88.—Adamson's Flanged Seam.

Fig. 89.—Paxman's Flue Joint.

objection to their use, however, lies in the facility offered for sediment and salt incrustation to gather and form in the hollows of the corrugations at the top of the flue, whilst at the bottom the corresponding hollows under the fire are filled with dead ashes, not easy to remove.

The method of fitting Galloway tubes in the flues consists in making a hole in the upper side of the flue of such a size as to allow the flange of the small end of the tube to be passed through. The hole cut at the bottom of the flue is the net size of the bottom of the Galloway tube. A row of rivets is then driven all round the flanges through the flue. The lower flange of the Galloway tube is inside and the upper one outside of the flue as shown at H, in Fig. 90. Sometimes the Galloway tubes are welded into the flues and this is very effectual in preventing leakages at the joints. An objection to this plan is the large hole which must afterwards be cut in the flue, if it is found necessary to remove the tube, as the welded part must be cut away with it.

As shown at Fig. 90 the last two rings of an internal tube in a Lancashire boiler are rather smaller than the others, the last but one being tapered in form, the diameter at the small end being some six inches less than at the larger end.

The egg-ended boiler, as before stated, requires no stays whatever, owing to its shape at the ends. The pressure acting on flat surfaces, however, causes those surfaces to bulge out. All flat surfaces in boilers therefore require to be stayed.

In the Cornish and Lancashire boilers the only flat surfaces are the ends and these require to be stayed, with gusset stays or with longitudinal stays passing from end to end of the boiler, or it may be with both.

Gusset stays are usually made of a single plate of iron and this is fixed to the end plate and to the shell by means of angle irons on each side of the strengthening plate, and shown in Fig. 90 at E. The rows of rivets at the front end gusset stays may also be seen in Fig. 105.

There are usually five gusset stays over the flue and two under at each end.

Longitudinal stays are rods of iron or steel secured at the ends by nuts and

washers. One is shown at R in Fig. 90. When these stays exceed 20 feet in length they have a tendency to droop in the centre and must, therefore, be supported there by small brackets riveted to the shell.

In staying the ends, the object desired is to strengthen the plates and yet preserve a certain amount of elasticity. If made absolutely rigid the flues would not have sufficient freedom to expand.

The following table, taken from Sir John Anderson's *Strength of Materials*, enables us to compare the relative strengths of the different forms of riveted joint.

The strength of the solid plate is taken at 100.

RIVETED JOINTS.

Description of Joint.	Riveting.	Rivet Holes.	Percentage of Strength of the Solid Plate possessed by the Joint.
Lap	Single	Punched	55
		Drilled	62
Lap	Double	Punched	69
		Drilled	75
Butt, 1 Cover	Single	Punched	55
		Drilled	62
Butt, 1 Cover	Double	Punched	69
		Drilled	75
Butt, 2 Covers	Single	Punched	57
		Drilled	67
Butt, 2 Covers	Double	Punched	72
		Drilled	79

From this table it appears that the single riveted lap joint is the weakest, that butt joints with one cover are no stronger than lap joints, but with two covers the percentage of plate strength is a little more than lap joints.

In the construction of boiler shells it has been proposed to substitute diagonal seams for the longitudinal, but an objection to this is the waste of plates resulting from cutting the ends to the chosen angle. Doubtless, a cylindrical boiler constructed with seams in this manner would be stronger than with ordinary longitudinal seams. A cylinder is twice as strong transversely as longitudinally.

In any boiler shell having the circular and longitudinal seams similarly riveted the former has twice the resisting power of the latter. A single riveted joint, unless badly designed and clumsily made, is rather more than half as strong as the solid plate. A single riveted ring seam is, therefore, calculated to resist pressure equally as well as the solid plate of the same thickness in the longitudinal section. In whatever way the longitudinal seams are riveted they cannot be made as strong as the solid plate and consequently the strength of

any boiler to resist internal pressure is limited by the strength of its longitudinal seams. If, instead of forming any longitudinal seams at all, the plates are cut so as to form an angle between the circular and the longitudinal the strength of the joint must be increased, the amount of increase being greater the more nearly the circular is approached. It is true that the effect of a diagonal seam replacing a straight longitudinal one would, while adding to the resisting power longitudinally, also weaken it transversely.

As the ring seam is so much stronger than the straight longitudinal, however, a boiler formed with diagonal seams would be, on the whole, stronger to resist internal pressure, and taken altogether the alteration would be a gain.

Boiler-plates are now made of such a size as to admit of one forming a ring, and possibly the amount of waste in cutting a diagonal seam on it would not be of so much consequence as the increased gain in strength obtained by it.

The diagonal seams would be formed by double riveting and be placed above the water-line, thus ensuring a considerable increase in the total strength of the boiler, if the angle formed between the ring and longitudinal seam be well chosen.

Some efforts have been made, too, to roll short, complete rings by special machinery, for boilers, but there appears to be considerable difficulty in practically carrying out this process.

Wherever an opening is cut in a boiler for a steam-pipe or any other fitting, an internal block is riveted round the opening to compensate, in some measure, for the diminished strength.

The man-hole is the largest opening in the boiler, and as this is usually elliptical in form, 16 inches by 12 inches, it necessitates cutting a large aperture in the boiler crown. At one time these man-holes were left without any strengthening collar, notwithstanding the danger arising from the diminished loss in strength of the plate. Afterwards it became the practice to rivet a broad strip of wrought-iron round the hole on the outside. The lid or cover consisted of a flat plate rolled to the curvature of the boiler. It was fitted to the inside of the shell and held up by bridge bars, bolts and nuts. With this arrangement it was very difficult to get a good fitting joint, as a great strain was brought upon the shell-crown by screwing the cover-bolts so tightly, the effect of which, increased by the steam pressure inside, was liable to bulge the cover sufficiently to fracture the edge of the man-hole. Rings of cast-iron were then tried, made to fit boilers of any radius, and these answered very well for moderate pressures. With increased pressures, however, these man-holes began to fail, and where the pressure is great the man-holes are now made of wrought-iron or steel. Besides the rigidity of cast-iron, which does not permit the man-hole to stretch as the more elastic wrought-iron or steel will do, cast-iron man-hole mouth-pieces may contain hidden faults such as blow-holes in the body of the metal. The present practice is to strengthen the aperture by riveting a broad strip of wrought-iron or steel round the inside of the hole, and fitting above it a short cast-iron, or, if for high-pressures, a wrought-iron or steel-flanged neck. This neck or mouth-piece is made flat on the top and has a slightly curved cover, secured to the neck by bolts and nuts passing through the flanges.

Boilers should be placed absolutely level in their seatings, or be very slightly inclined to the front. Usually they are fixed with an inclination of 1 or 2 inches in the length, the fire end being the lower, so as to have more water there than at the other end when at work, and to ensure the boiler being thoroughly emptied through the blow-off cock when desired.

This plan allows for any slight settlement which may afterwards take place in the boiler, causing the back end to drop. If the boiler be set exactly level and the back end afterwards settle down slightly, all the water would not flow out of the boiler through the blow-off cock when desired.

The objects to be aimed at in setting an ordinary Cornish or Lancashire boiler are:—

1. The circulation of the gases in contact with the shell, so that the heat of the fuel is utilised to its full extent.*

2. The distribution of these gases in such manner as to equalize the temperature of the shell as far as is practicable.

3. The arrangement of flues to give free access for a person to make an inspection of every part of the outside of the boiler.

4. The prevention of loss of heat by radiation from the surfaces not exposed to the hot gases.

Drawings Nos. 91—95 show the details of seating for an ordinary Lancashire boiler designed to meet these requirements. The products of combustion pass from the internal flues, as shown by the arrows, under the bottom of the boiler, and return by the side-flues to the stack. In constructing the side-flues great care must be taken that only the portion of boiler-plate which is below the level of the water inside the boiler is exposed to the direct action of the flames or heated gases. If the side-flues are so constructed as to allow the heated gases to come in contact with the plates above the water-line, there is danger of the plates being burned.

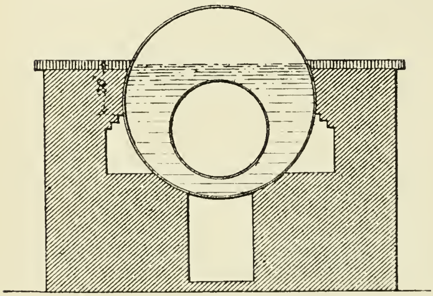


Fig. 96.—Faultily Seated Cornish Boiler.

The external flues are built of ordinary bricks, but it is essential that all parts of the seating exposed to the action of the fire should be made of good fire-brick, and the external flues are always lined inside with a thickness of $4\frac{1}{2}$ inches of fire-brick. In a range of boilers, the walls must be sufficiently thick between them to allow of one boiler being removed without injury to another.

It is of great importance to reduce as much as possible the actual contact of the brick-work with the bottom or sides of the boiler, as these points of contact are the most liable to deterioration. In some modes of setting there is no contact at all below the water-line, the boilers being suspended.

Care must also be taken in fixing boilers in the saddles on which they rest that some arrangement is made to allow for their expansion and contraction. For this purpose rollers are sometimes placed in the saddles.

There are a number of ways in which Cornish and Lancashire boilers have been at different times improperly seated.† Fig. 96 is a method of faultily seating a Cornish boiler, while Fig. 74 shows the most approved method of seating a similarly constructed boiler. In it properly designed seating blocks are used for the boiler to rest on, the point of contact between the two being over an extremely small area. To ascertain the supporting width in transverse section for the seating blocks where in contact with the boiler, allow one inch per foot diameter of the boiler; thus the seating blocks for a boiler 6 feet in diameter should be 3 inches on each side where in contact with the boiler, and for a boiler 7 feet in diameter $3\frac{1}{2}$ inches on each side. The crowns of the side flues should be built with proper quarter-circle tiles, and these as well as the seating blocks should be hard and of a non-porous nature, so that they may not absorb moisture and secrete corrosion. Above the crowns the brickwork should not exceed 6 or 9 inches.

Fig. 96 shows the boiler seated without either seating blocks or crown tiles, and

* See Report of the Chief Engineer to the Boiler Insurance and Steam Power Co., Manchester, June, 1881.

† For this comparison we are indebted to very able articles in the columns of the *Practical Engineer.*

the flue space formed by the brickwork is limited in extent and faulty in design. The seatings are built of ordinary fire-brickwork, are a foot broad, while the same kind of work is in contact with the boiler above the crowns of the side flues for 18 inches on each side.

The effect of so much brickwork in contact with the boiler renders the latter more difficult of examination, and being porous, it is calculated to absorb moisture and keep out of sight corrosion at those portions of the boiler shell covered by the brickwork.

Besides these objections to such masses of brickwork, there is the further one that the seatings formed in Fig. 96 deprive the boiler of a considerable amount of heating surface. In a boiler 28 feet long, the heating surface lost at the seatings would be $(1\text{ ft.}+1\text{ ft.})-(3''+3'')\times 28=42$ square feet as compared with Fig. 74. Allowing 10 square feet of heating surface per nominal horse-power the deprivation of heating surface results in a loss of 4·2 nominal horse-power in a boiler of the length given as compared with Fig. 74, and would be still more in one of greater length.

Again, the side flues of Fig. 74 being of ample size and suitable shape, offer no impediment to a full and searching examination when the boiler is not at work, and at other times ensures an efficient draught. The deposits of soot formed on the sides of the shell will fall to the floor, which being level or but slightly below the level of the lowest point of the boiler shell, allows of a certain amount of accumulation without greatly interfering with the draught, whereas in Fig. 96 thick deposits of soot still further reduce the capacity of the flues, and necessitate more frequent cleaning out than in Fig. 74.

To ensure a sufficient depth in the side flues further attention must be given to the form of seating block used. It is not sufficient that this presents a small

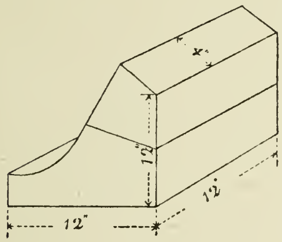


Fig. 97.—Seating Block.

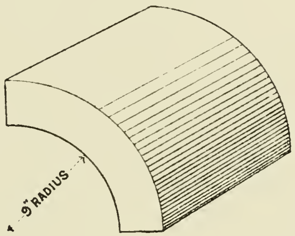


Fig. 98.—Closing-in Tile.

bearing surface for the boiler to rest on, for if made shallow and used for boilers of comparatively small diameter, the side flues formed as a result will be restricted in area. The seating blocks then must be of sufficient depth, as well as made to give narrow bearing surfaces for the boiler to rest on.

Fig. 97 shows a seating block suitable for a large boiler. Its inner vertical side next the boiler is 12 inches deep, by 12 inches wide at the bottom, and 3 inches thick in its outer edge, presenting a bearing surface of 4 inches at the portion in contact with the boiler plates. Opposite the ring seams, these blocks should be made in two parts as shown at Fig. 97, and the upper part left loose. This will facilitate examination for leakages at the seams of that portion of the shell resting on the blocks, as the loose portions of the blocks may be taken out, and after the examination is completed, re-placed.

The use of lime-mortar in any brickwork or blocks, actually in contact with the plates must be carefully avoided. The effect of using it in those positions is to corrode the iron, and therefore ground fire-clay is substituted to cement the fire-bricks and blocks in setting steam boilers. Fire-clay of good quality, such as that of Stourbridge, stands heat and sets well, and it has no injurious effect on boiler plates.

A suitable quarter-circle closing-in tile for the crowns of side flues is shown at Fig. 98. It has a radius of 9 inches, so that the width of the side flue at the top should be 9 inches, whilst at the bottom it should be constructed of such size as would enable a circle of 9 inches radius to be struck so that its circumference may touch the floor and side of the side flue, and also the shell of the boiler, as shown by dotted lines in Fig. 74.

Many other instances of improperly seated boilers besides that shown in Fig. 96 may be given.

Fig. 99 shows a case where, owing to limited space, a Cornish boiler was set without side flues.* Here the shell is completely covered by brickwork, allowing

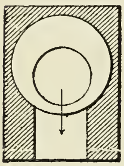


Fig. 99.

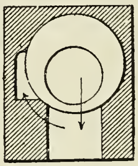


Fig. 100.

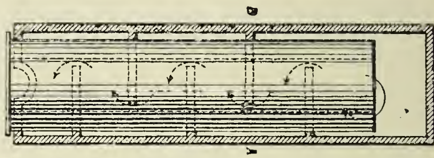


Fig. 101.

IMPROPERLY SEATED BOILERS.

of no opportunity of examination, and inducing corrosion to a dangerous extent without possibility of its being discovered.

Fig. 100 shows a Cornish boiler improperly seated with one small side flue and a bottom flue.

The effect of this on a long boiler is to cause springing and leakage of the seams from the heat being applied to one side of the boiler only.

Figs. 101 and 102 show a less objectionable way of seating a Cornish boiler in places where sufficient room cannot be obtained for side flues, but it is a wrong

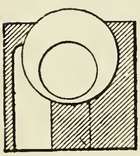


Fig. 102.

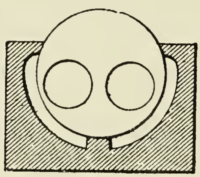


Fig. 103.

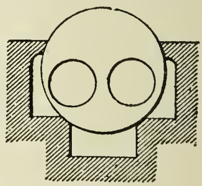


Fig. 104.

IMPROPERLY SEATED BOILERS.

mode of seating. Here the boiler is carried on cross walls, and the products of combustion coursed as shown by the arrows.

Figs. 103 and 104 show faultily seated Lancashire boilers where there has been sufficient room for the side flues, but no regard has been paid to giving access outside the shell.

Errors of this kind, shown in Figs. 103 and 104, may be corrected by removing parts of the brickwork, so as to enlarge the flues.

To prevent radiation of heat from the upper part of the shell, some kind of external protection must be provided. For this purpose boilers are too often entirely covered with brickwork, but this practice is very objectionable. It renders the upper portion of the shell inaccessible for examination, and should a slight leakage take place at a joint of one of the fittings, most probably it would not be detected until the moisture resulting from it had spread over a considerable surface of the shell, owing to the absorbent porous brickwork.

* See Report of the Chief Engineer to the Boiler Insurance and Steam Power Co., Manchester, June, 1881.

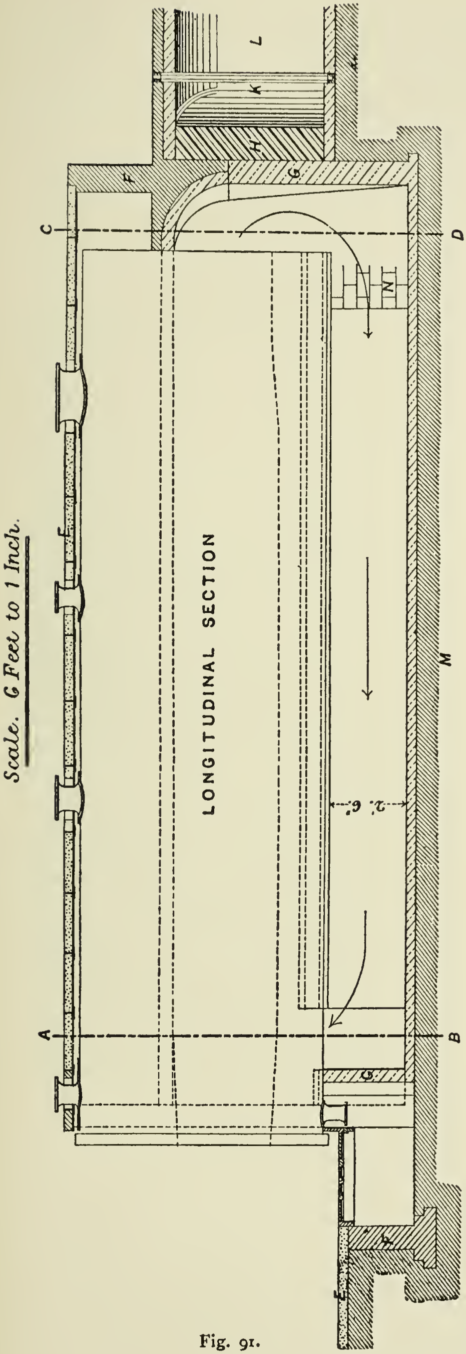


Fig. 91.

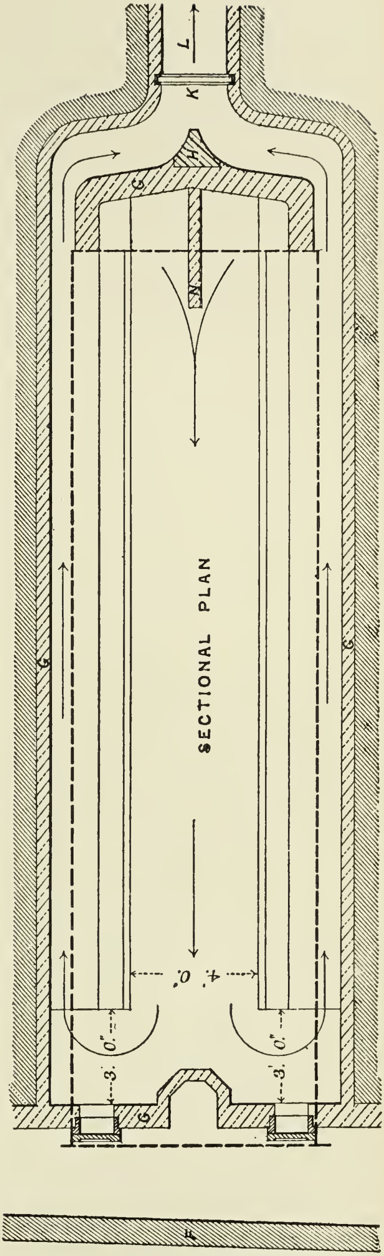


Fig. 92

THE SEATING OF AN ORDINARY LANCASHIRE BOILER.

The effect of damp brickwork in contact with the boiler plates is to cause damage to the plates by external corrosion. It is quite possible for this to remain undiscovered until it causes an explosion of the boiler.

Sometimes the upper part of the shell is covered by a "lagging" of wood stuffed with sawdust, but this practice is no more to be admired than a brick-

Scale. 6 Feet to 1 Inch.

SECTION THROUGH LINE A.B

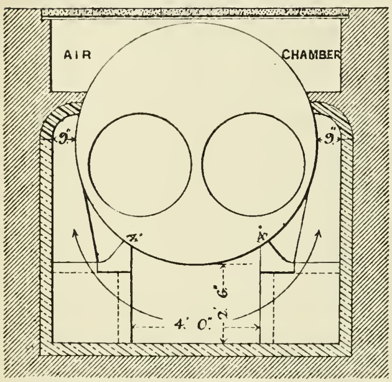
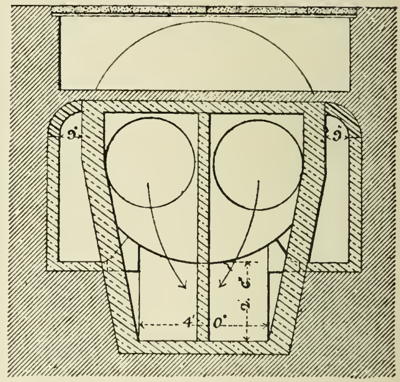


Fig. 93

SECTION THROUGH LINE C.D.



ig. 94.

ALTERNATIVE ARRANGEMENT OF COVERING

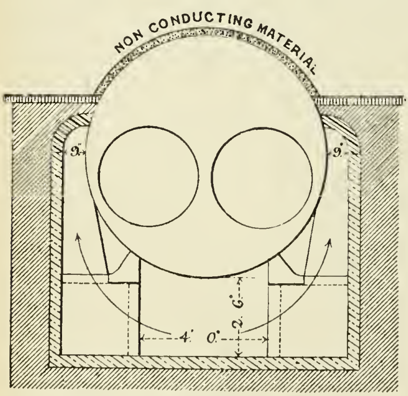


Fig. 95.

FRONT ELEVATION OF LANCASHIRE BOILER

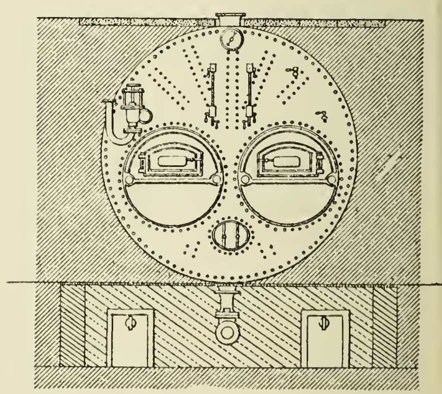


Fig. 105.

THE SEATING OF AN ORDINARY LANCASHIRE BOILER.

work covering. Coverings of patent felt and fibrous substances, which are bad conductors of heat, are much to be preferred to the previous-mentioned methods of external protection. An objection, however, to the use of these coverings is, that they do not admit of the detection of leaks so readily as in uncovered boilers. The best and most approved arrangement of external protection is that of providing a chamber closed in by thick tiles as shown in Figs. 91—94.*

This method renders the upper portion of the shell quite accessible at any

* See Report of the Chief Engineer to the Boiler Insurance and Steam Power Co., Manchester, June, 1881.

time for examination. Fig. 95 shows an alternate method of covering with some good non-conducting material, but it is not nearly so good a plan as that shown in Figs. 91—94.

Besides a separate covering for each boiler, a general roof covering should always be provided over boilers, to protect the whole range of boilers and fire-holes from the weather.

In explanation of Figs. 91 and 92,—

E shows the chamber-tiles, and floor-tiles at fire-hole.
F Ordinary brickwork.
G Firebrick walls or linings.
H Fireclay shaped blocks.
K The damper suspended by a chain passed over a pulley, at the other end of which is a damper counter-weight not shown in the drawing.
L The chimney flue, or a flue leading to a main chimney-flue.
M Concrete bed or ordinary brickwork.
N A short $4\frac{1}{2}$-inch partition-wall dividing the downtake into two compartments. Its object is to prevent baffling of the draught where the gases from the two internal flue-tubes unite. The absence of this wall may cause annoyance.

It will be observed (Fig. 91) that a proper recess is formed giving access to the blow-off cock and facility for its inspection. The practice of bedding the blow-out pipe in the wall is to be condemned. The upper course of brickwork, G, at the front end is shown $4\frac{1}{2}$ inches thick, or it may be brought up 9 inches thick to within a few inches of the boiler plates and there reduced to $4\frac{1}{2}$ inches, so as not to increase the area of brickwork in contact with the plates beyond what is absolutely necessary.

Care should be taken in setting the boiler to allow a clear space of one or two inches between the shell angle ring and the floor-plates at the front end; at the same time the shell angle ring should itself project about an inch beyond the front cross-wall, so as to be clear of the brickwork and open to inspection. In a range of boilers the main flue should be such a size as to afford a sectional area of not less than 5 square feet for each boiler of the range. In the case of a single boiler the width should not be reduced to less than 2 feet, on account of the difficulty of cleaning it, &c.

In some cases, the downtake, instead of being covered in with the quarter-circle tiles shown in Fig. 91, has a flat cast-iron cover plate for the purpose. It is of sufficient size to reach across the diameter of the boiler and the two side-flues. In boilers having a good draught the products of combustion issue from the flue-tubes at a high temperature, which the crown tiles are unable to resist beyond a limited time, after which they are fractured and allow the downtake to fall in. The cast-iron plate is a more expensive covering as regards first cost, but where the temperature of the escaping gases is high, is much more suitable.

With regard to the position in which boilers should be placed on the surface, circumstances must decide. In selecting the situation, it will be well to bear in mind one or two points.

Low and damp situations cause moisture in the flue brickwork, and where these situations cannot be avoided, the importance of preventing any damp from reaching the plates resting on the seatings is manifest.

A comparison of Figs. 74 and 96 shows without much reflection that the former is much better calculated to resist ill-effect to the boiler shell resulting from a damp situation, than the latter. In Fig. 96 the broad seat receives any leakage water from the boiler side above, which it readily absorbs, and the moisture yielded from the damp situation is very likely to find its way to the same point, where it lodges against the shell and causes external corrosion, which is hidden from view. In Fig. 74, leakages from the boiler sides would not be so liable to

remain in contact with the shell at the seating blocks, nor would moisture from the damp situation be likely to reach the shell at all, as the top of the blocks is considerably above the side flue floors.

The front of the boilers should be parallel with and close to a railway or siding, so that coal may be brought and ashes removed conveniently, and to prevent loss of heat in pipes, the nearer the boilers are to the engines the better.

Boiler fittings.—A *manhole* large enough to admit of a person getting into the boiler to inspect its condition and do any necessary cleaning or repairing. A *blow-off cock* usually placed in front of and below the level of the boiler; a pipe leads from the bottom of the boiler, the end of the pipe being closed by a valve able to withstand the pressure of steam. The blow-off cock, on being turned, allows the water from the boiler to run through this valve. The *water-gauge*, Fig. 106, is a thick glass tube placed in the end of the boiler, one end of which communicates with the steam space above the level of the water in the boiler, the other end below the water level. It thus indicates the level of the water in the boiler. It is

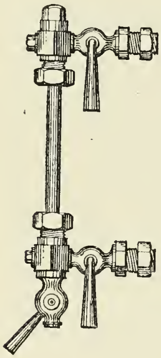


Fig. 106.—Water-gauge.

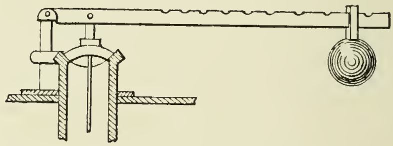


Fig. 107.—Lever Safety-Valve.

usually provided with a cock at each end by means of which it may be cut off from connection with the boiler, so that in case of a broken glass, the steam and water can at once be prevented from escaping and a fresh glass inserted. There is another cock at the lower end of the tube by which means the water in the tube can be allowed to escape from it. Another plan for ascertaining the level of the water is to place two *gauge-cocks* in the end of the boiler, the one being two or three inches higher than the other, the one being above and the other below the water level in the boiler. If the water is at its proper height steam should issue from the upper one on opening it and water from the lower one. These gauge-cocks should always be placed on the boiler in addition to the water-gauge. Still another method of ascertaining the height of the water in the boiler is by means of a *float* resting on it and communicating with a chain passed round a pulley above the boiler, at the end of which is attached a weight moving up and down with the float in the boiler. One of the most important of the fittings is the *safety-valve*, Fig. 107. The necessity for this is evident, for an engine may stand a considerable time, during which the pressure inside the boiler goes on increasing, and if some provision were not made for its escape an explosion must occur. The safety-valve should be placed directly on some convenient portion of the surface of the boiler, in preference to being attached to the pipe leading from the steam-valve, as often seen. The most common form is the lever. The valve is kept close by means of a lever fast at one end and having a sliding weight at the other, and near the fixed end a spindle passing through the valve, resting in its seat, communicates with the boiler. The

objection to its use lies in the fact that it sometimes gets corroded and sticks in its seat, and it is being supplemented by the use of dead weight and spring-valves.

Fig. 108 is a sketch of Hopkinson's Double Safety-Valve, designed to guard against either excess of pressure or deficiency of water. The valve is placed in a dome to protect it from injury, as shown in the Fig. The part B has a curved surface accurately fitting the top of pipe C, which is in direct communication with the boiler. The weight A slides along the lever, and may be adjusted to the required pressure. The float D is so adjusted that when the water in the boiler is at its proper level, the lever on which it is suspended is in a horizontal position, and the valve is closed. If the level of the water falls below its proper position, the float D sinks, and at the same time raises the valve by means of the spindle under it, thus allowing the steam to escape. In some instances as it blows off, this steam is made to sound an alarm whistle calling the attention of the boiler attendant.

All boilers should have two safety-valves, or a safety-valve and an *escape-valve*, the latter allowing the steam to escape on attaining a certain pressure.

A good plan is to fit a boiler with a Hopkinson's Double Safety-Valve and a Hopkinson or Cowburn Dead-Weight Safety-Valve.

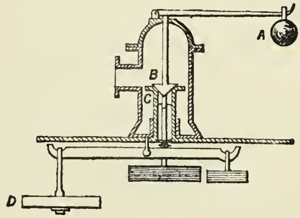


Fig. 108.—Hopkinson's Double Safety-valve.

The *feed water-valve* is so arranged as to allow the water to flow into the boiler, at the same time preventing any from returning. It is used to regulate the supply of water to the boiler.

The *steam, crown, or stop-valve* regulates the supply of steam from the boiler to the steam-engine, and it may be closed or opened by means of a screw worked by a hand-wheel.

Dampers are placed in the flues to regulate the draft on the furnace, and these are hung by chains passing over pulleys with balance-weights attached.

A *fusible plug* is sometimes employed to guard against the risk of explosion. A short nozzle is attached to the boiler just below the lowest level at which the water may safely stand. On this there is screwed a cap, the central portion of which is composed of an alloy which melts at a temperature not very much exceeding the boiling point. So long as this plug is kept covered with water it remains firm, the heat being carried away from it by the water, but should the level of the water fall so low as to expose it, the centre at once melts, and allows the steam and part of the water to escape into the flues and furnace, damping or extinguishing the fire, and at the same time removing the undue pressure. An objection to its use is, that it cannot be relied on after being in some time, as it becomes incrusted or injured by the heat and loses its efficacy. The *pressure* or *steam-gauge* is the means by which we ascertain the pressure of the steam. Mercurial gauges were at one time employed, but now "Bourdon's" is chiefly used. In this there is a dial-plate with a hand on it pointing to the pressure. The steam acts upon a spring of peculiar construction, causing the index hand to move according to the steam pressure, and the figure at which the hand points denotes that the pressure inside the pipe to which it is fixed is that much above atmospheric pressure. Thus, if the hand points to 20, we know that the pressure of steam is 20 lbs. above that of the atmosphere. A pressure-gauge should be fixed to each boiler, and one also to the main steam-pipe common to all the boilers of a range. In Chapter XIV. of this work pressure-gauges are more particularly referred to.

A *mud-hole* placed near the lowest part of the boilers. In the Lancashire boiler

it is placed in the front end-plate; the orifice is oval in shape, and its cover is occasionally removed for the discharge of sediment.

The furnace of a Cornish or Lancashire boiler consists of the mouthpiece, having doors provided with a sliding grid, shown in Fig. 105. The furnace bars are made in two lengths as shown in Fig. 90. At the front end these bars rest upon the dead plate, and at the back at a slightly lower level so that the bars may incline inwards. They are supported by the fire-brick bridge, either on a ledge formed on the bridge for the purpose, or a bearer built in it. In the middle at the joint of the two lengths the bars are supported by a cross-bearer. The bridge is usually built entirely of fire-brick to within about 20 inches of the crown

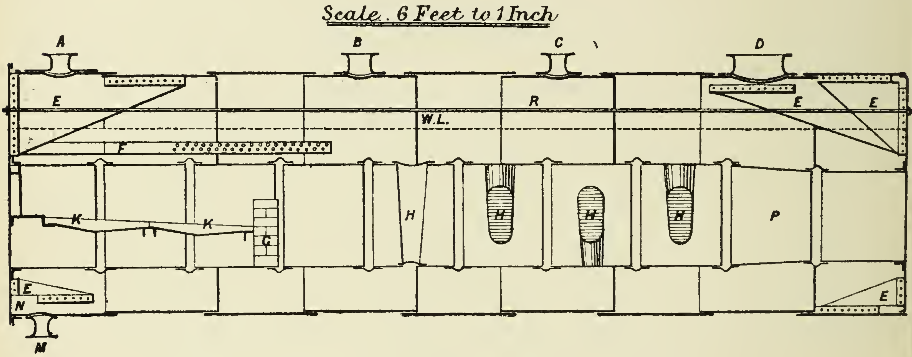


Fig. 90.—Longitudinal Section of a Lancashire Boiler.

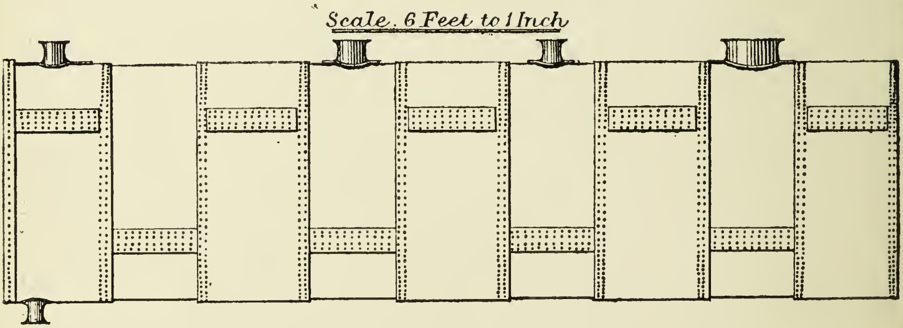


Fig. 109.—Side Elevation of a Lancashire Boiler.

of the internal flue, but sometimes a cast-iron stool is used to carry both the furnace bars and the fire-brick. The stool is provided with a sliding door, by means of which the admission of air to the furnace flue is regulated from the furnace mouth.

Some furnaces have a self-feeding arrangement. The coal in these is placed in a hopper above the furnace at the front end of the boiler, and a small revolving scoop driven by an engine constantly and slowly sprinkles the coal into it. A slow motion is also imparted to the furnace bars, so that the burning fuel is gradually carried to the back of the furnace as fresh coal is supplied in front. The objection to this plan is the complicated nature of the mechanism and the power required.

In the Bennis and also in Proctor's Mechanical Stokers the coal is distributed over the fire by flaps or shovels.

Fig. 90 shows a longitudinal section, Fig. 109, a side elevation, and Fig. 105, a front elevation of a Lancashire boiler, the seating for which is shown in Figs. 91–95.

In Fig. 90, A and C are blocks for the safety valves, a dead weight safety valve to be placed at A and a Hopkinson's double safety valve at C.

B is the block for the stop valve, to which is also fitted a perforated or anti-priming pipe inside the boiler, but not shown in the drawing.

D is the manhole block. It is usually oval but sometimes circular in shape, and is large enough to admit a man to the interior of the boiler to clean or repair it. It is placed in any convenient position at the top of the boiler.

E are gusset stays.
R longitudinal stay.
WL the water-level in the boiler. Modern practice fixes the low water line at 4 inches and the working level at 9 inches above the furnace crowns.
H Galloway tubes.
K Furnace bars.
G the fire-brick bridge.
P The internal flue, the rings being welded and connected to each other by the Bowling hoop expansion joint.
M the blow-off block.
F The feed pipe extending about 8 or 10 feet into the boiler, and having the inside portion perforated to allow of a gentle distribution of water all round it.
N a mud-hole for the discharge of sediment from the boiler, shown also in the front elevation, Fig. 105.

In Fig. 105 will also be seen the feed-water-pipe and valve, two glass water-gauges, two gauge cocks, the furnace doors, blow-off cock, and the cleaning flue doors.

Lancashire boilers to work at 110 lbs. per square inch are at present made of the following dimensions:—

Length 30 feet. Diameter of shell 8 feet. Diameter of internal tubes 3 feet 3 inches. Number of shell rings 9, made of mild steel having a tensile strength of 30 tons to the square inch. Two plates in each ring $\frac{5}{8}$ inch thick; circular seams, lap-jointed double zig-zag riveted, $3\frac{1}{4}$ inches pitch, $1\frac{1}{4}$ inches line to line; horizontal seams butt-jointed with inside and outside strap plates $\frac{1}{2}$ inch thick, pitch $3\frac{1}{16}''$, $1\frac{7}{8}$ inches line to line in the outer lines, $2\frac{1}{2}$ inches line to line in the centre line. Rivet holes $\frac{15}{16}$ inch, all drilled in position. Diameter of rivets $\frac{7}{8}$ inch, of mild steel machine-riveted. End plates of mild steel $\frac{11}{16}$ inch thick, the back-plate flanged, the front single riveted to shell angle iron 5 inches by 3 inches by $\frac{3}{4}$ inch. Internal tubes of mild steel $\frac{7}{16}$ inch thick, 3 feet 3 inches diameter, the plates having a tensile strength of 22 tons per square inch. Internal tube rings hand-welded, flanged and attached by $3\frac{1}{2}$ inches by $3\frac{1}{4}$ inches, by $\frac{5}{8}$ inch angle irons to the end plates.

Five gusset stays at the front and back end plate above the tubes and two below, and one centre gusset. The boiler subjected to a hydraulic test of 250 lbs. to the square inch.

A boiler should be tested to at least double the pressure it is intended to work at before being sent from the works, a hydraulic pump being used for the purpose, and a close examination for leakages being maintained throughout the test.

Insufficient attention in many cases is given to the various pipe connections.*

* The following observations respecting steam-pipe connections and expansion joints are, to a large extent, drawn from the columns of the *Practical Engineer*.

The principal connection of a steam boiler is the steam pipe. The steam from the boilers should pass into the main pipe direct, or into a receiver of large size from the top of which the main pipe afterwards leads. The receiver or main pipe crosses over the boilers at right angles to their length, and each boiler of a range should have a separate connection with the receiver. The receiver should have no inclination either way, and some provision must be made for expansion and contraction of the pipes. The steam pipes should be protected from loss of heat by radiation, and for this purpose a covering of patent felt may be placed over them. Sometimes the receiver is supported by pillars from the boiler walls, rollers being placed on the pillars for the receiver to rest on and to permit of expansion and contraction.

Fig. 110 shows the usual form of expansion joint used for steam pipes. It consists of an ordinary stuffing box and gland, and provides for longitudinal motion in the pipes by allowing them to slide in and out to an extent depending on the expansion and contraction which take place, and at the same time remain steam tight. In any long length of straight pipes which are not subject externally to upward or downward pressure or strain, and having no connection with them

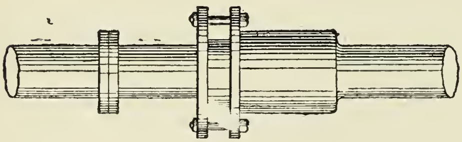


Fig. 110.

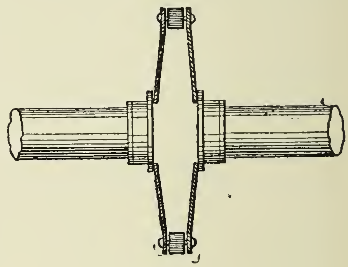


Fig. 111.

Steam-Pipe Expansion Joints.

except at the two extremities, this expansion joint renders good service, the pipes being free to expand and contract without interference by side strains. These expansion joints, nevertheless, require attention, as the material with which they are packed wears, and so causes leakages unless renewed when necessary.

Fig. 111 shows another form of expansion joint, which it was thought would be an improvement on that of Fig. 110. In it two thin diaphragms are secured at their outer circumference to a block ring which is about 2 inches thick. The central portion of each diaphragm receives the steam pipe at its inner circumference, and as the diaphragms are thin and considerably larger in diameter than the pipes on either side, they form an elastic joint. As the steam pipes expand or contract the diaphragms approach or recede from each other, at that portion which is joined to the steam pipes.

It is very questionable whether this form of expansion joint is any improvement on that which it was designed to supersede. The steam in its passage along the pipes enters the space formed between the diaphragms with considerable force, and the pressure arising therefrom tends to separate the diaphragms, which may at the same time be subject to other motion resulting from expansion and contraction of the pipes. To ensure the necessary elasticity, the diaphragms must be made thin; if too thin they are unable to stand the force of the different pressures acting on them, and so give way.

In arranging a system of steam pipes from the range of Colliery boilers several points call for consideration. Frequently the main pipe is connected with the boilers as shown in Fig. 112, but it is an arrangement not to be recom-

mended. The motion to which a boiler is subjected is transmitted to the connections made with it, and when at work there is continual expansion and contraction taking place, which will change in accordance with the firing of the boiler and the consequent change in temperature and steam pressure. In a range of boilers these changes will be irregular at all times, and be most marked on laying the boilers off for cleaning, or repairs, and on re-starting them. Any tendency on the part of the boilers to revolve in their seats, following from expansion and contraction, causes a strain on the pipe joints and flanges, which, if severe enough, fractures them.

The boilers of a range are also subject to unequal settlement in their foundations, which is followed by a strain on the steam pipes; this will be more or less injurious to the joints according to the distance between boilers.

In a range of boilers having the steam pipes connected with them as shown at Fig. 112, the effects of expansion and contraction on the steam pipes may be slightly guarded against by fixing an expansion joint between every two boilers of a range. But this will not be sufficient to remedy the evils of all possible

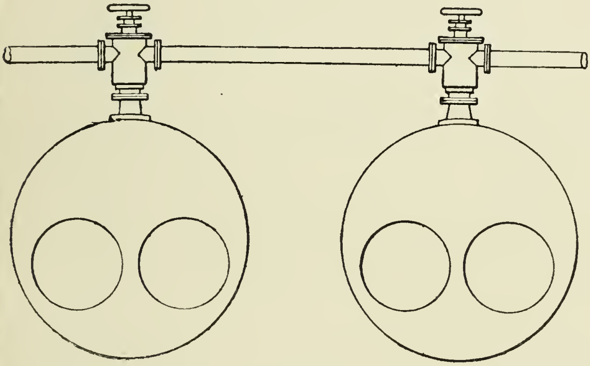


Fig. 112.

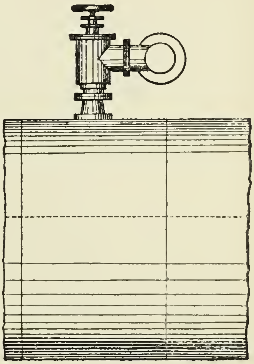


Fig. 113.

Undesirable Methods of Connecting Steam Pipes with Boilers.

strains, and in a range composed of many boilers introduces a constant source of anxiety to the boiler attendant, who will have considerable difficulty in keeping so many stuffing boxes in order and steam tight. On account of the attention required to prevent leakages at expansion joints, the aim should be as far as possible to dispense with their use.

Fig. 113 shows another arrangement of steam pipes which in this case are carried across the range of boilers close to the stop valve, and the objections urged against Fig. 112 apply with equal force to the arrangement shown at Fig. 113.

A method of connecting the steam pipes to a range of boilers free from the objections given to those just described is shown in plan, at Fig. 114, and, in elevation, at Fig. 115. Here, the main steam pipes cross the range of boilers at right angles at a distance of 7 or 8 feet from the stop valves, and a branch pipe at right angles to the main pipe is laid from each stop valve to the main pipe. To a very large extent this provides for unequal settlement of the boilers at their foundations. The motion caused by the settlement of one boiler is transmitted to the branch pipe, but while the full effect of the settlement is felt at the stop valve end of the branch pipe, the strain resulting at its other end which is fixed to the steam pipe will be slight, and may be provided for by not carrying the main pipes on fixed, unyielding

supports from the boiler walls. These should be carried on rollers placed on springs which, while allowing for longitudinal expansion and contraction in the pipes, would also yield to the motion transmitted by the branch pipe,

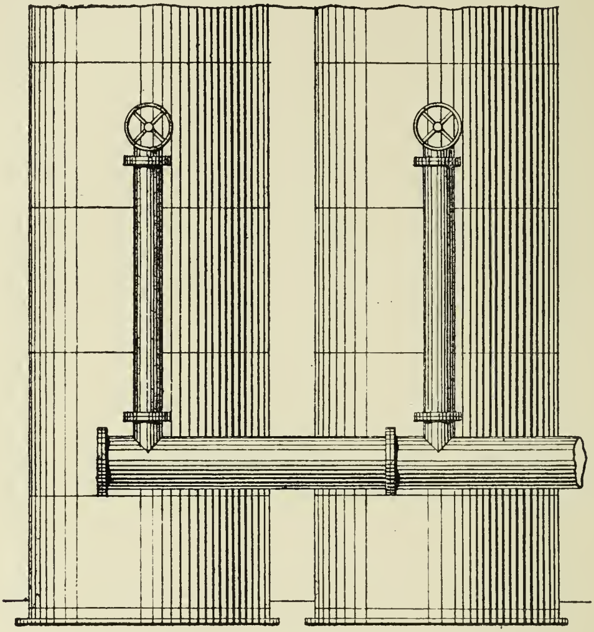


Fig. 114.—Approved Method of Connecting Steam Pipes with Boilers.

and in turn convey it to the branch pipe on either side of that first receiving motion.

The use of expansion joints may be altogether dispensed with by providing springing lengths in the pipes. Where practicable, bends may be placed at right angles to act in this way, either along the course of pipes or at the two extremities. Where this method cannot be pursued, a horizontally laid U-shaped bend may be introduced between the two boilers at both extremities of the range. As variations in temperature proceed, the legs of the U will be acted on so that the two ends move slightly nearer to, or further from each other.

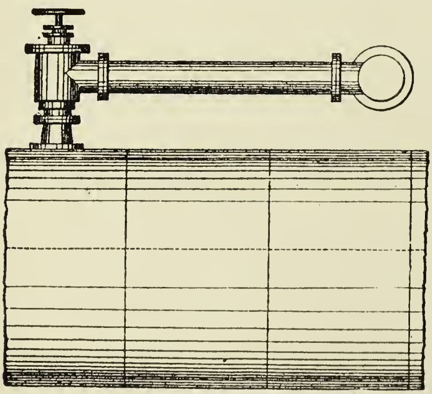


Fig. 115.—Approved Method of Steam Pipe Connection.

Fig. 116 shows another method of laying the steam pipes from the boilers which is nearly as effective as that shown in Figs. 114 and 115, and is suitable under circumstances that prevent the arrangement there shown, such as irregularity of line in the stop valves resulting from boilers of a range being added to from time to time, or obstructions crossing a line which would otherwise be chosen at the stated distance from the stop valves.

In this case the branch pipes forming the connection to the main pipe, instead of being straight, are curved and doubled back, as shown in the figure.

Whichever system is adopted, the bends of the U's where placed at the two

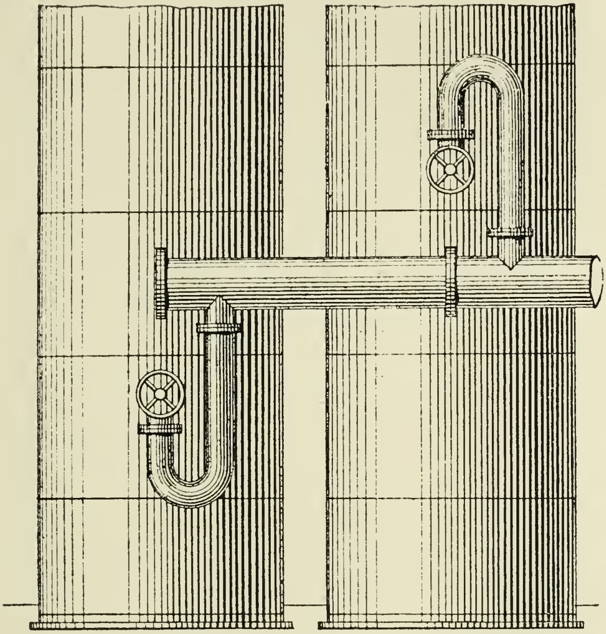


Fig. 16.—Approved Method of Connecting Steam Pipes with Boilers.

extremities of the steam pipes, and the steam pipes themselves across the boilers, should be laid horizontally, in order to avoid all lodgment of water in the pipes. If the steam pipes cannot be continued in a horizontal position to the engines, they should be slightly inclined towards them and any water formed through condensation be removed by separators, or steam traps.

Where the steam pipes are not laid on a level with the stop valves, some means have to be devised to overcome the difference in level, but it can never be so good an arrangement as that which places the stop valves and steam pipes on the same level.

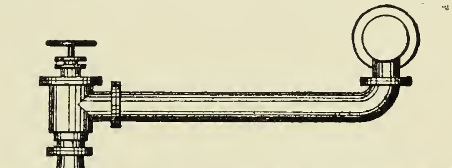


Fig. 117.—Means resorted to through neglecting to place the Main Steam Pipe on a level with the Stop Valve.

Fig. 117 shows a plan sometimes adopted to overcome this difference of level. Under ordinary working conditions it may work effectually, but when one boiler of the range is idle the branch pipe becomes a receptacle for condensed water, necessitating the use of a drain pipe and tap, which must be

fixed under the branch pipe, and so add to the cares of the already fully burdened boiler-attendant.

Where steam is generated on the surface and conveyed in pipes down the shaft, expansion-joints should be placed at suitable intervals—ordinarily about 50 yards—in the shaft. As the pipes form a long straight line in the pit, the ordinary expansion-joint is usually adopted and found to answer well.

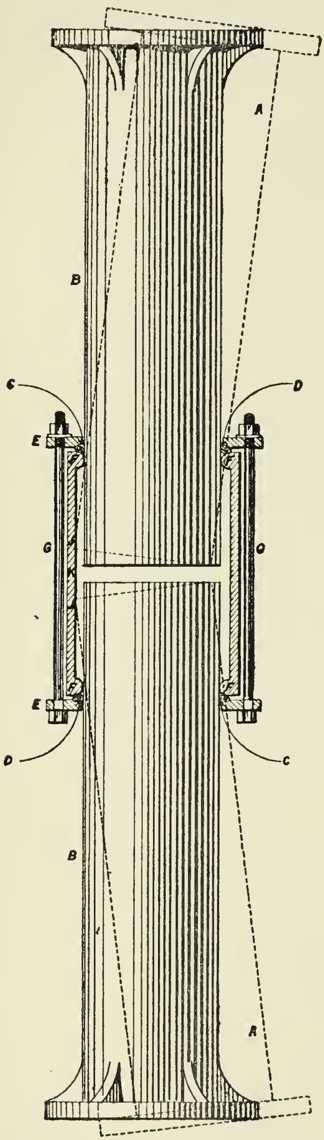


Fig. 118.—Steam Pipe Expansion Joint for Underground Roadways.

If the pipes have to be continued from the bottom of the shaft into the underground workings along roadways which are subject to disturbance, either from lateral pressure or upward or downward variations of the floor and roof, the ordinary expansion-joint is unsuitable, because it does not yield to the road disturbances sufficiently to prevent injury or breakage to the pipes and consequent blowing at the joints.

Fig. 118 shows an expansion-joint especially adapted for allowing air,* steam or water pipes to accommodate themselves to the irregularities of underground roadways. A ring or cylindrical casting, K, is made with internal projections, F, at each end, of such size as to pass freely over the outside of the pipe B B. These projections are about $\frac{5}{8}$ or $\frac{3}{4}$ of an inch, and allow the ends of the pipe to move to the inside of the ring at J J, and by so doing the pipe, if 9 feet long, can be placed from 9 inches to 18 inches out of a straight line, as shown in dotted lines at A A, without at all affecting the security of the joints at D D. The joints D D are made by placing india-rubber rings over each end of the pipe B B, and to ensure their having a thoroughly tight grip of the pipe, the india-rubber rings must be smaller than the external part of the pipe B B. The ends of the cylindrical ring K are grooved out at F, and so also are the inside of the loose flanges E E, so that the india-rubber rings C C are kept firmly in place and cannot be blown out by pressure.

After all parts are put in their places, the through-bolts G G are screwed tight, when the joint is completed, ready for use.

Any pipe may be used for putting on the expansion-joint by cutting 5 or 6 inches out of the middle, or two old or broken pipes may be taken if one flange of each is good.

The joint being simple is quickly made, as it requires no special connecting-pipes when joining new pipes, and when replacing an old one it need not be exactly the same length as the one removed; the length of the pipe may be varied a few inches by pushing it in or drawing it out of the expansion-ring K.

* See Transactions, South Wales Institute of Mining Engineers, vol. XVI. pp. 188, 189.

The feed-water should be conveyed to the boilers hot. The temperature of the water in its passage along the pipes is not high enough to cause inconvenience from expansion and contraction of the pipes, and no expansion-joints are needed. The exhaust steam is often used to heat the feed-water before the latter passes into the boilers, but unless this is done without allowing the steam to mix with the feed-water it is objectionable, as the grease and dirt pass from the cylinders into the boilers and so into the cylinders again and again. There are various methods of utilising the heat in the exhaust steam, most of which consist of passing it through pipes surrounded by the water-tank out of which the feed is supplied or by reversing the arrangement. Formerly feed-pumps were used to force the water into the boilers, and this was frequently done without raising the temperature of the water before doing so. The water entered the boiler through a pipe at the top and extended downwards a little, terminating in an open-mouthed pipe. Where the water has to be brought from a distance or from any point below the level of the boilers, pumps worked by small engines may still do most useful work, but they are not much used to pump the water direct into the boilers. The usual practice is for the pump to deliver the water into a tank placed a little above the level of the boilers, unless the water will reach the tank by gravitation. After the temperature of the water has been raised in the tank, it is conveyed by means of injectors to the boilers; or, if an exhaust injector is used, the temperature of the water is not raised in the tank, but enters this form of injector at 90° F. or lower.

The injector is lighter, occupies less space, and absorbs less power than a feed-pump, and is quite as reliable in action, with the further advantage of coming into action only when required.

Injectors may be divided into two classes, viz., live-steam injectors and exhaust-steam injectors. The action of both is somewhat strange, and has puzzled many engineers. In the former the water is forced into the boiler by the pressure of live steam direct from the boiler acting on the surface of the water in the injector, under certain conditions. In the latter the same object is attained by the use of exhaust steam, also under certain conditions.

M. Giffard invented the injector many years ago, and it was introduced into this country by Messrs. Sharp, Stewart & Co., whose works were formerly at Manchester, but have been removed to Glasgow. This form of injector is still the most generally used, but it is not applicable to all purposes. Although Giffard's injectors are stated to draw water from the supply, they all, but more especially the small sizes, work better when placed below it, so that the water may run to the injectors by gravitation. The pressure of steam to work the injector must not be under 5 lbs., nor must the pressure against the water being forced into the boiler be more than twice the pressure working the injector. It cannot be employed when the temperature of the feed-water is above 135° F. for low pressures and 105° F. for the highest pressures, as a part of its efficacy arises from the condensation of the steam. If therefore these temperatures are exceeded, a large volume of water is required to condense the steam, and the effect of this is to reduce the velocity of the steam in driving forward the large body of water. To work efficiently under the conditions named, the regulators require very careful adjustment.

The following particulars are furnished by the Patent Exhaust Steam Injector Co., Limited:—

"The Giffard Injector was the first ever made, and the improved form of the original instrument, shown in Fig. 119, has been proved by experience to be a reliable apparatus, simple to work, and not liable to get out of order. Having self-contained steam and water regulators, it will work at a greater range of steam pressure than any other class. It may be fixed either above or below the

level of its supply water, and the fixing can be done by any local engineer or mechanic.

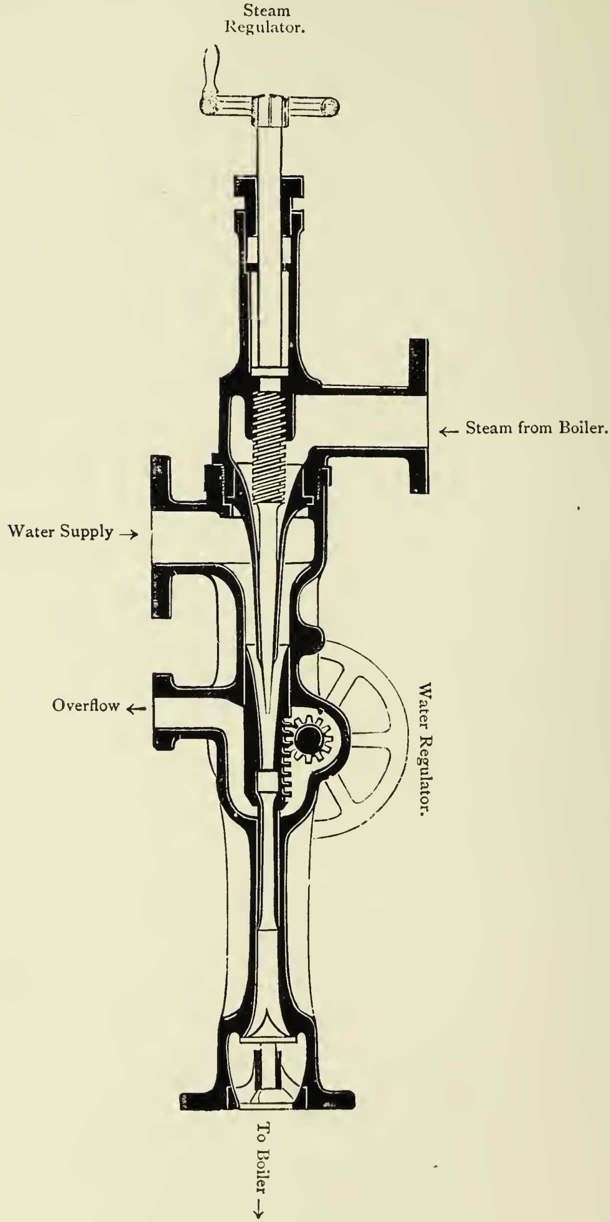


Fig. 119.—The Giffard Injector.—Class A.

"Among its advantages are the following:—

1.—Small first cost, the absence of all working parts in motion, and the consequent small repairs.

2.—It supplies water to the boiler without the necessity of working the steam engine, and in a continuous stream instead of intermittently as with a pump.

3.—The steam admitted to the injector is condensed and re-enters the boiler with the feed water, thereby raising its temperature, so that only hot water enters the boiler, and the straining of plates consequent on unequal expansion when pumping in water at a low temperature is avoided.

4.—The consequent saving of the power required to work pumps, as well as of their wear and tear, which, in the case of donkey-engines especially, is considerable.

5.—The freedom from risk of damage or stoppage by frost.

"Very many thousands of these improved injectors are at work all over the world, and the makers confidently recommend them as being in all respects most complete and efficient, and certain to give the greatest satisfaction to steam users in all countries. Having all the progressive number books in their possession, exact duplicate injectors of these and all other classes made by Sharp, Stewart, & Co., Limited, can only be obtained from their sole successors, The Patent Exhaust Steam Injector Co., Limited, 4, St. Ann's Square, Manchester.

"*Instructions for Fixing.*—The injectors may be placed horizontally or vertically, with connecting pipes. There must be a continuous supply of dry steam, with a cock or valve on the steam-pipe to the injector. The water-supply must be continuous, and should not be hotter than 135° Fahrenheit with low pressure, or 105° Fahrenheit with the highest pressures. The delivery to boiler is of course much hotter than this. The injector may be placed either above or below the level of the water-supply; the small sizes will draw from 2 feet to 5 feet, and the larger ones 12 feet. There must be a back-pressure valve on the delivery pipe to the boiler. The water-supply pipe must be perfectly air-tight. A cock or valve is only required on this pipe when the water flows to the injector, and has to be shut off when not working.

"*Instructions for Working.*—Open the cocks on the steam- and water-supply pipes. Open the water regulator and slightly open the steam regulator until water issues from the overflow, after which, open it fully and the water will be forced into the boiler. If all the overflow is not taken up when the steam regulator is fully opened, adjust the water regulator to stop this. The water regulator should be turned to its full extent occasionally, to prevent its setting fast. The quantity of water delivered to the boiler may be reduced when the injector is working, by turning down the steam regulator until there is an overflow, and taking this up as usual by the water regulator.

"Steam from the boiler passes through the top branch pipe where shown on the drawing, and is admitted to the injector through a conical nozzle. The lower end of a vertical spindle fits accurately into the nozzle, and an ascending or descending motion may be given to this spindle by means of the screw actuated by a hand-wheel at the top. The admission of steam may be thus regulated. The feed-water enters the injector on the opposite side from the steam and flows through a branch pipe at a slightly lower level to the steam-pipe branch, as shown in the Fig. It passes round the outside of the conical nozzle to meet the steam which rushes in with great velocity; the steam is condensed and a partial vacuum formed, into which the following steam rushes with great velocity, to be in its turn condensed, but the water is carried along with it, and the energy is so great that the water is forced into the boiler notwithstanding the pressure against it. The water supply is regulated by the hand-wheel shown at the side. It works a small pinion inside the injector, and, on being turned, moves a tube up and down. Provision is made by means of a branch pipe placed below the level of the feed-water branch, for the overflow water. A back-pressure valve is

placed at the bottom of the injector, and on the side of the boiler not shown in the Fig. a check-valve is placed, which prevents the escape of water when the injector is not in action."

The difficulty of understanding the action of the injector arises from the fact that the steam is able to drive the water it meets in the steam-cone into the boiler against a pressure equal to or greater than its own.

The explanation given in Prof. Jamieson's *Text-book on Steam and Steam-Engines* is as follows:—If two jets issue under the same pressure, one of steam and the other of water, the velocity of the former will be many times greater than that of the latter, and if steam, in its passage from a boiler, is condensed to water, but not reduced in velocity to that of water issuing under the same pressure, it is then able to overcome the pressure of water in its own boiler. In the Giffard injector, the meeting of the steam and water in the nozzle causes condensation of the steam without its losing its velocity, except that due to the friction of the passages. The partial vacuum, caused by the condensation, is followed by more steam, which rushes in with great velocity to meet more water in the nozzle; condensation follows, and the feed-water in advance is carried on by the force of the condensed steam-jet into the boiler. The velocity of the steam-jet is necessarily reduced by imparting a high velocity to this volume of water, but it is not reduced nearly so low as that of a jet of water issuing under the same pressure, and hence it is capable of overpowering and forcing back the water in the boiler.

There are many forms of live steam injectors, in which improvements have been attempted, the greatest of which is for the apparatus to work when placed above the level of the water-supply. The most that has been attained hitherto in this direction does not exceed 20 feet.

The Exhaust Injector is the invention of Messrs. Hamer, Metcalfe, & Davies. The feed-water tank must be placed at a slightly higher level to that of the injector. The latter may be anywhere connected to the main exhaust-pipes, but the nearer to the boilers the better. An elbow in the exhaust-pipes makes a convenient point of connection. As the exhaust steam passes along the pipes, the injector takes sufficient to supply its own wants without interfering with the course of the rest. It is capable of feeding any boiler working at not more than 60 lbs. pressure, so that when the exhaust steam is at atmospheric pressure, or 15 lbs. absolute, the feed-water opposes and overcomes a pressure against it of 60 lbs. per square inch.

The exhaust injector in no way affects the working of the steam engines. To start it, communication is opened with the exhaust steam and with the feed-water supply. It may be arranged to work as an ordinary injector so as to feed the boiler when the engine is standing. The temperature of the feed-water must not exceed 90° F.

The construction of the exhaust injector is different from the injector. In the former the exhaust steam enters the top of the injector and passes into a conical nozzle. This nozzle is fitted with a fixed conical spindle, the object of which is to concentrate and direct the flowing exhaust into a circular jet by the time it meets the cold feed-water, and so precipitate condensation. The feed-water enters a branch at the side of the injector near the top, and on flowing into the conical chamber surrounds the steam in its passage through the nozzle. Condensation begins as the exhaust and feed-water meet in the condensing chamber which forms the upper part of the hinged nozzle. The hinged nozzle imparts to the exhaust injector its automatic action. When not at work the nozzle hangs back, by this means giving space for the water and steam to meet. Immediately after meeting, condensation takes place, a partial vacuum is formed, and the hinged nozzle assumes a position which reduces the space through which the combined exhaust and feed-water pass.

The exhaust injector requires no attention, and is automatic in its action, starting and stopping with the engine to which it is connected. It is very efficient where engines work without stoppages, and is said to give good results even where engines do not run continuously, but whose motion is without interruption for several minutes at a time, and if a colliery winding engine runs sufficiently long during a period of winding, it may work satisfactorily with such engine. The waste steam, in passing through the injector, heats the feed-water to a temperature of about 190°. A saving in fuel from 15 to 20 per cent. is effected by the application of this injector as compared to pumping the water into boilers.

There must be the usual back-pressure valve on the boiler; and if the delivery-pipe is long, an additional back-pressure valve must be fixed two or three feet away from the injector.

It has been successfully applied to winding engines, fan engines, and hauling engines at collieries.

The main flue into which the smoke from the boiler is discharged leads to the chimney, which is necessary to create a draught. The main flue should have an area equal to that of the chimney at its base, unless more than one main flue discharge into it. The chimneys are larger at the bottom than at the top, the sides having a taper or batter of about 1 inch per yard. They are lined with firebrick for a considerable distance from the base. To determine the size necessary for the chimney, allow 5 square feet for each boiler, and let the height be equal to 25 times the internal diameter. Chimneys are built of many forms, but the circular seems to be the best.

The following table of round chimneys is taken from *Power Steam*:—

TABLE OF ROUND CHIMNEYS. Height equal 25 times diameter.

Diameter of Flue in Inches.	Height in Feet.	Rated H.P.	Lbs. of Coal per Hour.
24	50	49	245
27	56	70	350
30	63	94	470
33	69	124	620
36	75	158	790
39	81	197	985
42	88	242	1,210
48	100	348	1,740
54	113	478	2,390
60	125	632	3,120
66	138	810	4,050
72	150	1,023	5,115
78	163	1,265	6,325
84	175	1,531	7,655
90	188	1,830	9,150
96	200	2,167	10,835

For 10 boilers it would be necessary to have the diameter of the chimney at its base about 8 feet, and 200 feet high.

Besides the boilers already described which have hitherto been most in use at collieries, may be briefly mentioned a few other forms. The Breeches-flued or Duplex Furnace is a modification of the Lancashire boiler. In it the two furnace-

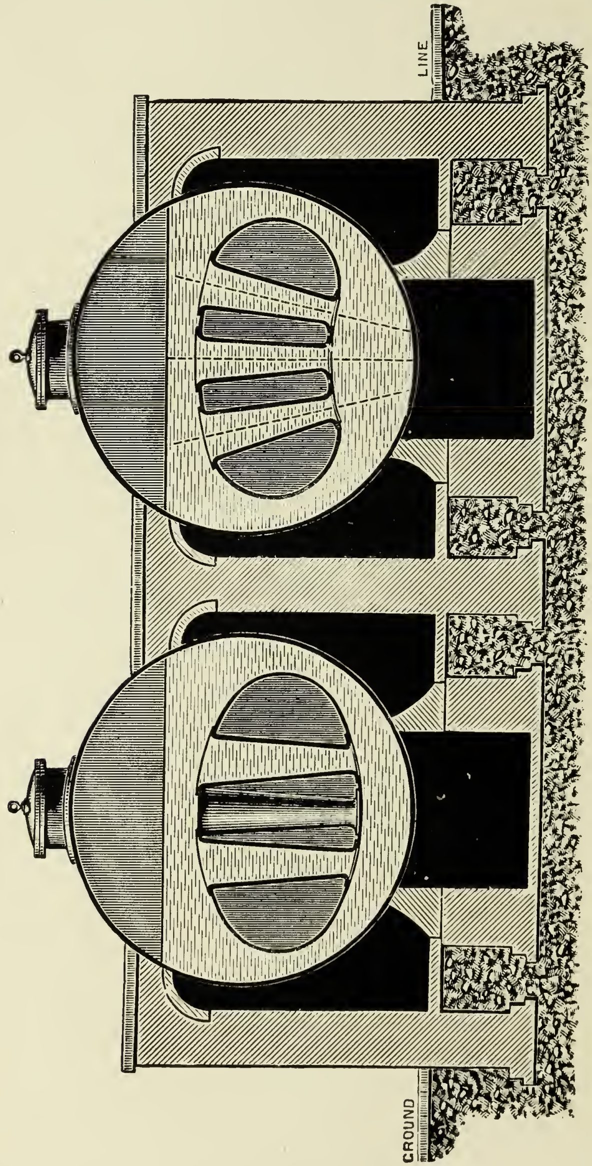


Fig. 120.—The Galloway Boiler.

As formerly made. On the latest patent.

tubes, instead of being continuous from end to end of the boiler, unite into one large cylindrical flue immediately behind the bridges.

The "Galloway" is a form of breeches-flued boiler. In it the large flue from the point of juncture with the furnace-tubes to the back-end plate is somewhat elliptical in section as shown in Fig. 120.

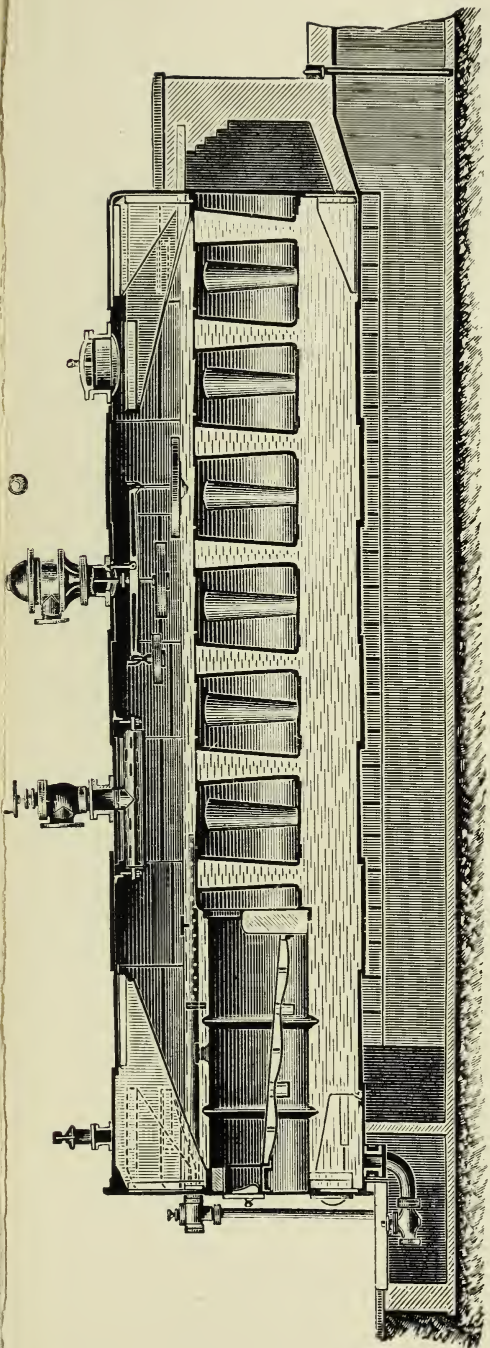


Fig. 121.—The Galloway Boiler. Longitudinal Section, with Fittings and Furnace Apparatus in Position.

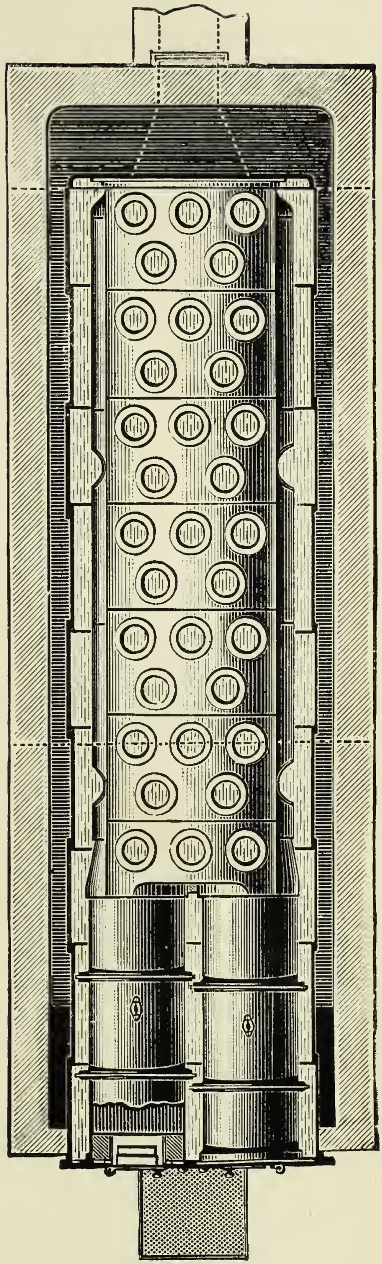


Fig. 122.—The Galloway Boiler. Plan shewing Disposition of Tubes and Brickwork Bed.

Galloway tubes are fixed three abreast and two abreast alternately throughout the length of the elliptical tube as shown in Fig. 122. As now made the central cone tubes are placed quite upright, as shown in Fig. 120, the others forming a slight angle with the perpendicular. Galloway boilers are made of steel 30 feet long and 8 feet in diameter to work at 100 lbs. steam pressure.

The particulars below are furnished by Messrs. Galloways, Limited, Manchester:—

"The following drawings from photos will explain the general arrangement and construction of the patent Galloway boiler, containing all the most recent improvements in design. This system of boiler has been in use for about 30 years, having been improved in many points of detail from time to time—the latest advance being the upward curve of the under surface of the back flue, and the radial arrangement of the cone tubes. The alteration thus effected gives more space for cleaning and examining the lower portion of the boiler, and allows the insertion of an increased number of cone tubes. The tubes themselves, moreover, are now made entirely by machinery, and with the flanges square to the centre line, which causes them to be interchangeable, and reduces the strain upon the iron in the manufacture.

"Reliable tests of the efficiency of steam boilers conducted under independent and competent superintendence are difficult to obtain, but on many occasions the Galloway boiler has been proved to give a higher result than any other in the market. We may, however, instance the official tests at the Philadelphia Exhibition of 1876, which were carried out by a special committee, and entirely without any interference or control being possible on the part of the makers of the boiler, where the Galloway boiler evaporated 11·72 lbs. of water, at a temperature of 212° per pound of coal; and also a test carried out at the mill of C. R. Collins, Esq., Hele, Devonshire, under the immediate supervision of the editor of *Engineering*, at which a result equal to 12·83 lbs. of water at the same temperature per pound of Welsh coal was attained. At Philadelphia, moreover, the quality of the steam generated was carefully tested, and, in addition to the highest rate of evaporation, the Galloway boiler was ascertained to give the driest steam. This is a matter of the utmost importance, as with perfectly dry steam there can be no risk of break-down occurring to an engine from that most frequent cause, priming.

"It has been ascertained in practice that a Galloway boiler is considerably more powerful than an ordinary two-flued or Lancashire one of equal dimensions, and as it burns the same amount of fuel it is correspondingly economical. A Galloway boiler 28 feet long by 7 feet diameter, when driving a condensing engine in fair order, is fully equal to 300 indicated horse-power, but in many cases one such boiler has regularly driven over 350 horse-power with compound engine, at a working pressure of 80 lbs. per square inch; this is considerably higher than can be obtained from a boiler of the ordinary construction."

Messrs. Galloways supply also the subjoined summary of official tests of boilers at the Philadelphia Exhibition, 1876, where thirteen boilers were tested for eight hours each, at a pressure of 70 lbs. to the square inch, "when the Galloway boiler gave the most economical result, and furnished the driest steam."

Description of Boiler.	Heating Surface in Square feet.	Horse-Power at 1 cubic ft. Water evaporated per Hour.	Lbs. of Water evaporated.			Per Centage of Water in Steam.	Lbs. of Coal Burnt.		Temperature of Gases leaving Boiler.	Cubic Feet of Water Space per Horse-Power.	Cubic Feet of Steam Space per Horse-Power.
			Total.	Per Hour.	At 212° per lb. combustible.		Per Hour.	Per Square Foot of Grate Per Hour.			
Galloway ...	973	14·64	20824	2603	11·72	·57	283	7·269	324	14·10	4·04
Root	1590	54·29	27146	3393	11·565	not taken	381	9·09	393	2·29	·89
Fermenich ...	1078	26·46	13233	1654	11·53	not taken	185	11·79	415	4·08	2·63
Lowe	774	21·45	10729	1341	11·489	not taken	153	6·805	332	9·02	2·63
Babcock ...	1680	62·70	31358	3919	11·489	3·24	444	9·77	295	3·74	2·20
Andrews ...	540	18·94	9469	1183	10·513	not taken	148	not taken	419	4·14	1·29
Wiegand ...	1355	68·08	34042	4255	10·461	not taken	517	12·32	523	2·66	·64
Anderson ...	1135	44·44	22230	2778	10·255	not taken	350	9·747	417	1·43	1·28
Kelly	662	37·41	18710	2338	10·099	5·97	291	10·82	not taken	1·91	·68
Harrison ...	900	36·57	18285	2285	10·022	1·11	284	12·36	517	1·93	·80
Pierce	200	23·74	11876	1485	9·818	5·53	199	7·99	373	·65	1·64
Exeter ...	1525	32·65	16334	2041	9·765	4·63	280	9·35	429	2·66	1·43
Rogers & Black	399	21·13	10564	1320	9·31	2·68	181	8·05	571	1·71	1·17

In the Water-tube Boilers the flame and hot gases from the furnace act directly on rows of parallel tubes of small diameter through which the water is passed, and a receiver is placed over the tubes for the steam given off in them. They are very rapid steam generators, and like other boilers have their advantages and disadvantages.

The following description of the Babcock and Wilcox water-tube boiler is taken from the *Practical Engineer* of June 22, 1888:—

"The exhibit of the Babcock and Wilcox Co., of New York and Glasgow, consists of one of their patent water-tube boilers, as illustrated above. It has 64 tubes, 4 inches diameter and 18 feet long, with a steam receiver 4 feet diameter by 22 feet 4 inches long, and is suitable for a working pressure of 180 lbs. per square inch. It is rated at 126 H.P., and is estimated to be equal to a Lancashire boiler 30 feet by 7 feet 6 inches at 150 lbs. pressure. The rated horse-power here means 30 lbs. of water evaporated from 212°, at 70 lbs. pressure for each horse-power.

"It will be seen that the boiler consists of a series of lap-welded wrought-iron tubes, placed zig-zag one over the other, and connected at each end by vertical headers to a steam and water-receiver placed above in a horizontal position; while below, at the back end, there is a cast-iron mud chamber or sediment-collector, to which is attached the blow-off. These four different parts, when fitted together, constitute the boiler, and it is by the ingenious combination of these that the present state of perfection has been arrived at.

"The tubes are connected with the headers by being expanded into accurately bored and tapered holes, the headers again being connected by tubes to a substantial riveted block on the under-side of the water and steam-receiver. This method is stated to give every satisfaction under all pressures and conditions.

"The receiver itself is a cylindrical shell of Siemens-Martin steel, double-riveted in the longitudinal seams, and single-riveted circumferentially. The end plates form the segment of a sphere, or are what is usually termed dished. This being the strongest form in which they can be made they do not require any further staying. The manhole, for internal examination, is placed in one end, and is formed by flanging the plate inwards and facing the edge, so that a metal-to-metal joint can be made.

"The vertical headers have been usually made of cast-iron, but the firm have on exhibition a wrought-iron one, similar in design to those in use, as shown in

Fig. 123. It is a beautiful piece of work, of great strength, and will considerably add to the confidence already placed in the safety of the boiler.

"The fire is placed under the tubes at the front end; the flames and heated gases rise to the under-side of the horizontal water drum, and thence pass downwards among the back portion of the tubes, and on to the chimney. There is no fear of any evil effects from this arrangement, as the boiler is suspended from above by means of hoops round each end of the steam and water-receiver, and is thus entirely free to move and accommodate itself to the variable movements consequent on expansion and contraction.

"The water level is about the centre of the receiver, and by virtue of the greatest heat raising the temperature at the higher end of the tubes it circulates rapidly upwards at the front, along the chamber, down at the back, and on through all the tubes.

"Owing to the rapid circulation, the greater part of the sediment has not time to deposit itself in the tubes or headers, but is carried onward until by gravitation

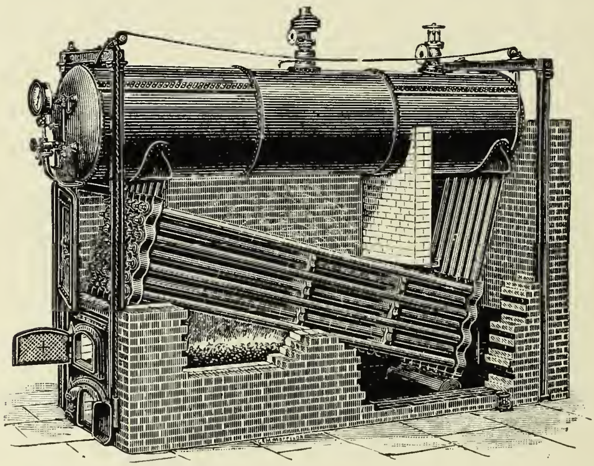


Fig. 123.—The Babcock and Wilcox Water-tube Boiler.

it reaches the lowest part of the boiler at the back, where it rests in the collector, and is blown out at intervals through the cock placed there for that purpose.

"There will, of course, be some deposit in the tubes, and this fact has not been overlooked. Opposite each tube, at either end in the vertical headers already mentioned, there is a small door, which is easily removed, and through which a scraper of improved construction is applied to the inside of the tube. This scraper, which we understand is the subject of a patent, accommodates itself to any unevenness, and is used from the front end, while the deposit is removed from the back or lower end of the tubes.

"These doors, which are also used in the construction of the boiler for expanding the tubes, have double joints, to ensure tightness and safety. The inside one has an indiarubber ring, and in case of the nut or stud breaking, or in any way becoming deranged, the pressure on the door presses it against the inside face, and so prevents leakage until a new door is got ready.

"For cleaning the outside of the tubes ample means have also been provided. In the side wall there are three long narrow doors, communicating with the different sections into which the flame space is divided. A flexible rubber hose, capable of withstanding 300 lbs. per square inch, is connected to the steam-

receiver, and the wrought-iron perforated pipe on the other end is put through the doors and among the tubes; the steam jets rapidly bring down the soot. For cleaning out there are large doors, as shown in the illustration; the one at the back is also for getting at the sediment collector. The fittings consist of a stop-valve, a safety-valve, two sets of water-gauges, a feed check-valve, a blow-off valve, and an improved pressure-gauge, on the Schäffer and Budenberg principle. Great attention has been given to the delivery of dry steam to the engine—a point of importance well known to all engineers. The absence of priming in this boiler makes the use of any special apparatus unnecessary; the only precaution to be taken is to place the stop-valve on the opposite end of the steam-receiver to that over the fire. The steam is, as it were, made at one end and discharged at the other, so that by the time it has traversed the receiver all particles of water in suspension have fallen out of it, and the steam is in a fit state to be conveyed to the engine without any further drying. We may say while referring to the steam space that, excepting under exceptional circumstances, the old idea of having a dome, or other storage for the steam, other than that contained in the boiler-shell proper, is quite wrong, and so long as ample water surface is provided for the steam to disengage itself easily, nothing further is required.

"So much for the construction and design of the boiler, and from what we have said it will be seen that the manufacturers have paid every attention to these particulars, even in the minutest details, and from the success that has attended their efforts to produce an efficient and safe steam generator, they have evidently not overlooked the many important features inseparable from efficiency and economy. The ratio of heating surface to fire-grate, and these two combined to the steam space, is based on actual experiments and nearly 20 years' experience. The result, as embodied in practice, is to be found in the continual efficiency of the boilers at work.

"The following figures are taken from records of trials that have been made:—

"In 1879 a trial of two boilers, 360 H.P., was made in America, when, from careful observation, the rate of evaporation was found to be at the rate of 9·2 lbs. of water per lb. of coal at a pressure of 70 lbs., and from a temperature of 180° with 12 per cent. of refuse.

"In 1883, at another trial in Pittsburgh, 10·9 lbs. of water were evaporated from each pound of bituminous coal—less 11 per cent. of ash—at a pressure of 70 lbs. from and at 212°.

"Again, during trials at San Francisco, with three different kinds of coal—viz., British Columbia, Welsh, and Washington—there were 11·1 lbs., 11·8 lbs., and 10·4 lbs. of water evaporated per pound of pure coal respectively. Efficiency trials have also been made in this country, and we extract the following from the company's report, dated July and August, 1885, regarding tests at the Gaythorn works of Messrs. J. and J. M. Worrall, dyers, Manchester, with a 140 H.P. boiler:—

	No. 1.		No. 2.
Heating surface	1,616 sq. ft.	...	1,616 sq. ft.
Grate surface, 6 ft. 6 in. by 4 ft. 6 in.	29 sq. ft.	...	29 sq. ft.
Ratio of heat to grate surface	55 to 1	...	55 to 1
Duration of test	27 hours	...	$18\frac{1}{2}$ hours
Average observed steam pressure	75 lbs.	...	95 lbs.
Average temperature of water fed to boiler by injector	135°	...	275°
Pounds of coal fired	25,536	...	11,704
Coal consumed per square foot of grate per hour	31·7	...	21·6
Total water evaporated	216,000 lbs.	...	118,400 lbs.
Water evaporated per hour	8,007 lbs.	...	6,400 lbs.

	No. 1.		No. 2.
Water evaporated per pound of coal—actual conditions	8·46	...	9·85
Rated H.P. (one H.P. = 30 lbs. of water evaporated from 212° at 70 lbs. pressure)	140	...	140
Temperature of flue gases	700°	...	680°

"In trial No. 1 the 27 hours include three stoppages, aggregating $2\frac{1}{2}$ hours, in which but little steaming could have taken place, so that the figures represent ordinary working conditions.

"From the careful manner in which the reports of the various tests of this boiler have been drawn up, it would appear that great care has been exercised to arrive at correct and reliable results."

Vertical Boilers are useful where only a small amount of power is required, but they are not economical steam producers. There are many varieties of vertical boilers; they are generally fitted with either Galloway tubes or parallel tubes to improve the water circulation in them and also to facilitate the escape of steam.

The truest economy results from in the first place obtaining boilers of the very best construction, and due attention having been paid to their seating, then giving constant attention to their preservation. It has been suggested that the working pressure of boilers should be reduced at regular intervals of time in proportion to their advanced age, and that some limit of age should be fixed beyond which they should not work at all. There are many objections to such an arbitrary course of procedure. The great difference in the quality of material used in the construction, and in the mode of setting a boiler as well as the subsequent care or neglect, render it impossible to frame rules which would be applicable to all boiler users without injustice to some. Boilers no doubt deteriorate with age, but in many instances practices are allowed to proceed which seriously increase the rate of deterioration and ensure a speedy destruction of the boiler. Where well constructed, well seated, and tended by careful and skilful men they have been known to work as long as 30 years at but trifling costs for repairs.

Again, it has been urged that as a safeguard against explosions, boilers actually at work should receive at regular intervals a similar hydraulic test to that applied when new. In some cases it may be beneficial to use the hydraulic test to a working boiler, as for instance immediately after it has undergone repairs and before re-starting work. All defects that are visible should be found by periodical inspection to which undoubtedly boilers should be subjected, but it is questionable if good results would follow an application of the hydraulic test used to search for defects which exist but are hidden. Its effect *may* be only to increase the defects without detecting them, and consequently the boiler on being set to work again with its weaknesses intensified, is in a worse state than before, and may have suffered so much from the treatment as to be unable to stand the usual working pressure and so explode on its being attained.

Only a good maker using the best materials will ensure the production of a reliable boiler, designed so as not to have too much rigidity in one place, or too great elasticity in another. When the fire is first lighted in the furnaces the front end may be seen to come out as much as $\frac{3}{4}$ of an inch from its position when cold. The furnace crowns also rise up as much as $\frac{1}{2}$ an inch from the expansion, and if proper provision has not been made in a Lancashire or Cornish boiler for the elasticity of the ends, what is known as *grooving*, *channelling*, *furrowing* or *guttering* round the furnace-tube angle-irons may begin.

Grooving is the eating away of boiler-plates in lines or furrows, and is caused by the mechanical action proceeding at the point of grooving, assisted by the chemical action of the feed-water. In the lap-joints (and at the angle-irons) which are subject to much bending and straining motion, grooving frequently takes place, the plates being corroded in a line parallel to the joint and just at the beginning of the lap. The effect of grooving is to weaken the plates, and frequently to fracture their ends about the rivet-holes.

Expansion and contraction are constantly present in a working boiler, and as they cannot be controlled, provision must be made in the construction of the boiler to meet the varying temperatures, or the mechanical action resulting therefrom may cause fractures.

If Lancashire boilers are seated and protected against radiation of heat in the manner already suggested it will tend materially to their preservation.

Then the manner in which a boiler is worked and tended, the quality of the feed-water used, and its treatment, are important factors affecting the durability of the boiler.

A boiler attendant should be a man of intelligence who knows something of the construction of that which is placed in his charge. Careless, untrained, and underpaid attendants ruin good boilers in a variety of ways: for instance, by neglecting to feed the furnaces, thus allowing the fire-bars to get bare, a passage being thereby formed through which the cold air passes; by driving the furnaces too much and generating steam rapidly, afterwards opening the furnace doors in order to prevent blowing-off at the valves; by using means when being laid off to quickly cool the boiler instead of waiting till the brickwork is cool before running the water out, and allowing time for the boiler to cool gradually; by filling or partly filling it with cold water immediately after it is emptied; and on the boiler resuming work, by forcing the fires and raising steam more rapidly than should be attempted from cold water. Intense firing should specially be avoided in boilers having thick plates.

Care is required in hand-firing boilers, otherwise much smoke is emitted. The fuel should be introduced frequently and in small quantities which must be spread thinly and evenly on the front portion of the fire-grate, and at intervals the hot fuel pushed back. No portion of the grate should at any time be bare so as to form an air-passage through the fire.

Every boiler should be thoroughly emptied of its contents periodically, say once a week or once a fortnight according to the water used, and afterwards be filled by an entirely fresh supply.

All natural water contains more or less of foreign matters and is therefore never pure. The impurities may be gaseous, mechanical, mineral, or organic; one class will predominate in one locality and another elsewhere. The purest water obtained is rain-water, but even that is charged with the atmospheric gases oxygen, nitrogen and carbonic anhydride. In 100 parts of water there are about 2 parts of air, but the amount varies slightly. Next to rain-water in point of purity is that which flows over soil which is not easily absorbed, or which receives no other soluble matters than those washed down by the rains, such as that of mountain torrents, and rock-protected lakes.

Gaseous impurities in waters result from the strata through which they flow. Part of the rain which falls upon the surface of the earth is evaporated again into the air, another portion finds its way directly to the surface streams, whilst the remainder sinks into the earth's crust, to afterwards issue at the surface in the form of springs. Where the course taken by the water in following the natural fissures is tortuous and long, it may pass through rocks of varying character and composition. All waters have great capacity of absorption, and in consequence of flowing through strata favourable to it, they become charged with

large quantities of gases; as for instance, in the waters of Bath, Harrogate, Llandrindod, &c.

Mechanical impurities are those mixed with and suspended in the water arising from its passage through or over the earth. They consist of soil, chalk, sand, silica, &c., which are insoluble in water and therefore incapable of absorption. They not only affect the purity of the water, but also its nature, making it either *hard* or *soft*.

Mineral, or chemical impurities in waters result from their passage through or over the earth, and are those most commonly found. They consist of carbonate of lime, carbonate of magnesia, potash, soda, sulphate of soda, alumina, in varying proportions, according to the nature of the soil. Water impregnated with iron is said to be chalybeate. The presence of the salts of lime and magnesia renders water hard.

Organic impurities in water arise from animal and vegetable organisms, either living or dead.

Glasgow is partly supplied with water from Loch Katrine which in point of purity compares favourably with that of any city in the world, while the water supplied to London is obtained from the river Thames and contains nine times as many impurities as that from Loch Katrine. The water used for domestic purposes in the town of Pontypridd is for the most part derived from a mountain torrent, and shows on analysis about double the impurities of the Loch Katrine water.

The water available for boilers should be first submitted to careful analysis by a competent chemist, and if found to be of good quality, it may require no treatment, except a little soda or other alkali occasionally; but if pronounced impurities exist, efforts must be directed to neutralise their effect, and these must be guided by the analysis.

The effect of supplying boilers with water containing only mechanical impurities is to have a deposit of mud formed in the boiler, and although this is not so objectionable as an incrustation, the water should not be allowed to enter the boiler, unless some means are afterwards taken to remove it before the sediment forms a deposit. Where no provision is made to purify water of this description either before or after it enters the boiler, it necessitates frequent blowing off and cleaning. If no other impurities are present in it, the water may be greatly improved by being filtered before it enters the boiler, as water percolating through sand is divested of much of its mechanical impurities.

Waters which have mineral impurities require certain chemicals added to them to change their character, and as far as possible prevent them from forming deposits within the boiler, and from wasting the plates by internal corrosion. The amount of cleaning necessary in the boiler will depend on the success of the chemical treatment.

An incrustation formed in the boiler interposes a bad conductor of heat between one side of the boiler plates and the water at a point where the other side of the plates is exposed to the fire, and so predisposes to explosion.

Soda or almost any other alkali may be used in water which contains sulphate of lime, which will then be converted into a carbonate and form a soft scale which may be easily removed.

Some benefit is derived, where impure water is used, by frequent blowing off and so getting rid of matter which if allowed to remain, would form into scale. This method is wasteful as compared with purifying previous to heating the water.

Carbonate and sulphate of lime and carbonate of magnesia form the larger part of ordinary scale found in steam boilers.

The salts of lime and magnesia in the form of carbonates are easily dissolved in water which contains carbonic anhydride. In water raised to the temperature of 212° F. carbonic anhydride is driven off, and the maintenance of the same or

an increased temperature is followed by the salts being deposited on the interior of the vessel in which the experiment is conducted. In steam boilers the result of such a deposit is to form scale.

If a similar experiment be tried with water which contains sulphates of lime or magnesia, it will be found that the salts will not be deposited on the water reaching a temperature of 212° F., and it is not until the temperature has increased to 300° F. that the water loses its power of holding the sulphates in solution, after which

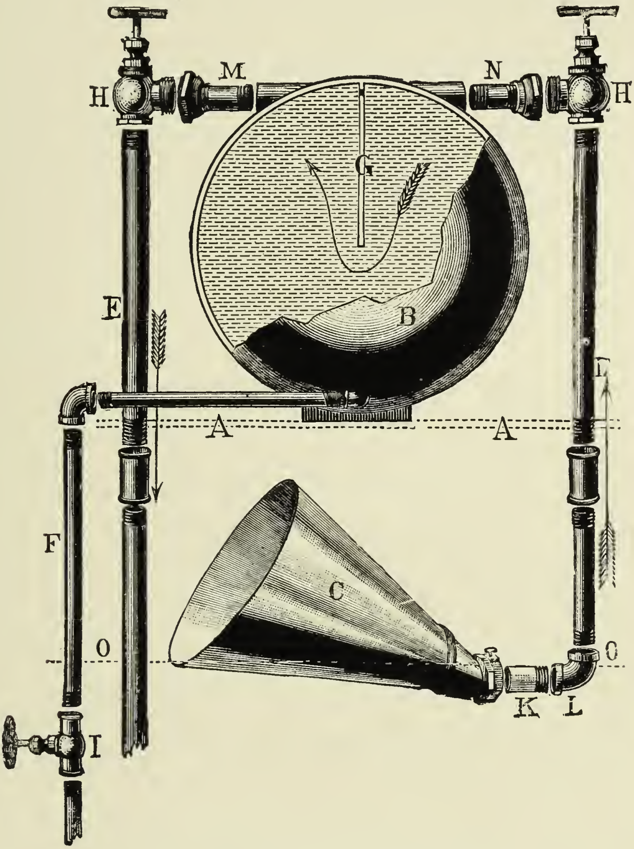


Fig. 124.—THE HOTCHKISS BOILER CLEANER.

they are precipitated on to the surface of the vessel as were the carbonates at a lower temperature. A pressure of about 55 lbs. corresponds with a temperature of 300° F., so that any boiler working at that pressure is liable to have scale formed on the plates if the feed water contains the carbonates or sulphates of lime or magnesia.

A number of anti-incrustation compounds are manufactured for the purpose of preventing the water impurities forming into a scale on the boiler whilst the compositions do not themselves injure the plates. The addition of a compound to act chemically after the water is in the boiler, no doubt in some instances renders the deposit formed in the boiler softer and therefore easier removed, but to be effectual the composition must contain elements, specially arranged to com-

bine with the impurities in that water wherein it is placed. It is impossible therefore for any one composition to eliminate all kinds of impurities from water.

Elaborate and more costly methods of purifying water—such as the "Porter Clark," the "Stanhope Water Purifier," &c.—may be adopted for removing the salts of lime and magnesia from the water before it is passed into the boilers.

Where the feed-water is of a muddy description the Hotchkiss Boiler Cleaner, Fig. 124, as described by Mr. Horatio Nelson, 90, Worship Street, E.C., is said to be very effectual in removing scum and the floating deposits in the water.

In Fig. 124 the double dotted line AA is the top of boiler shell, which usually is found to be the most convenient position to place the reservoir. The reservoir is connected with the funnel C by the up-flow pipe D, and to a lower part of the water in the boiler by the return pipe E. Through these pipes and the reservoir a circulation is established which flows in the direction shown by the arrows. The funnel C is set within the boiler on the low-water line, as indicated by the dotted line OO. G is a diaphragm in the reservoir to divert the flow of water therein. F is the blow-off pipe, for removing the deposits B from the reservoir. HH are two valves, used to shut off reservoir from boiler if required. Angle valves, as shown, are generally used to simplify the connections. I is a valve on blow-off pipe F. K is a socket nipple, secured by thumb-screw. M and N are nipples, each with half-union to complete the connection.

This cleaner is automatic and, from natural causes, certain in its action.

The manner in which the "cleaner" acts in removing sediments from, and preventing scale formation, in steam boilers, is as follows:

As soon as the water in a steam boiler becomes heated, currents are established; these currents are formed by the hotter, and therefore lighter, water flowing upward and away from the source of the greatest heat, while the colder, more dense water flows to the source of heat, to replace the other, and in its turn becomes heated.

In all boilers where fire is applied at one end, the currents established will be upward and from the fire on the surface, and downwards and towards the fire in the lower part of the boiler.

In a boiler with the cleaner attached, the funnel C is set near the surface of the water, but partly submerged, and in such position that its opening will intercept the currents of hot water flowing towards it.

By the syphon action of the apparatus the hot surface water containing any floating matter that enters the funnel is caused to pass through the up-flow pipe D into the reservoir, thereby displacing the cooler water therein, which flows back to the boiler through the return pipe E, which terminates at a lower level than the funnel.

By this means, so long as firing is kept up, a constant circulation is maintained and all the water in the boiler is caused to pass through the reservoir. The water while in the reservoir is comparatively quiet, and entirely free from the agitating currents within the boiler, and while in this quiescent state the contained sedimentary matter B is precipitated, and remains in the reservoir, from which it can be blown as often as necessary by the pipe F.

The action of this apparatus creates a current in the boiler, thus utilizing the usual cold strata of water lying under the flues, and which is useless for creating steam.

Every one familiar with steam boilers is aware that deposits and incrustations seek naturally the quietest part of a boiler. The office of the Hotchkiss Mechanical Boiler Cleaner is, therefore, simply to provide a place for their accumulation, outside of the boiler itself, and removed from heat and its agitating effects; from whence they can be readily removed as fast as they accumulate, instead of shutting down the boiler to clean them out by hand, or by blowing

down the boiler in the ordinary way, thus losing a large amount of water already heated to the steaming point, which is wasteful as to fuel, and also a great loss of time.

It is not claimed for the "Hotchkiss Mechanical Boiler Cleaner" that it will

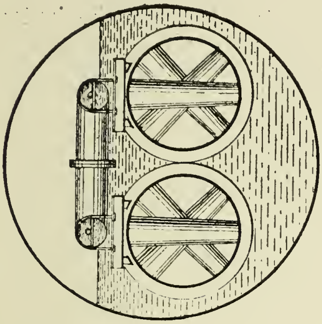


Fig. 126.

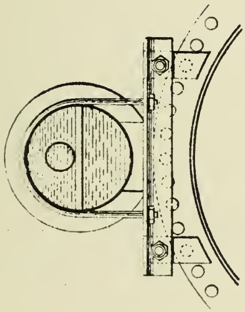


Fig. 127.

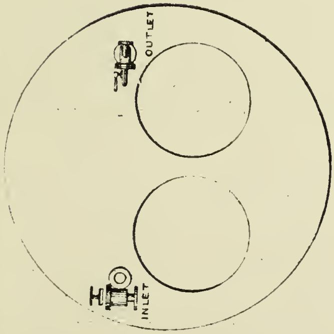


Fig. 125.

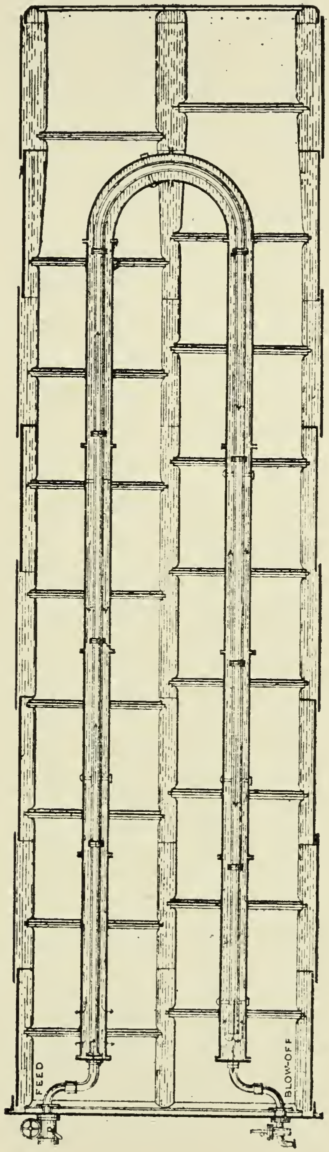


Fig. 128.

Seale's Patent Water-purifier.

remove scale bodily from the boilers when the scale is already formed, but it is claimed for it, and *guaranteed* that it will prevent the formation of new scale by removing all the floating deposits and mineral salts, which become scale if not

removed from the water before they have had time to adhere to the heating surfaces.

By preventing the formation of new scale, the old, by expansion and contraction of the heating surfaces, soon becomes loose and readily detached.

A simple means of purifying the feed water before it enters the boiler is by Seale's Patent Water Purifier, shown at Figs. 125–128, as applied to a Lancashire boiler. Fig. 125 is a front elevation, Fig. 126 a sectional elevation, Fig. 128 a sectional plan, and Fig. 127 a detail view, showing the mode of carrying the pipe.

The feed water enters through the feed valve at the front end, and traverses a length of about 50 feet of 2-inch piping, arranged in the form of a horseshoe. This pipe is enclosed within a larger one of about 8 inches in diameter, suspended near the working level of the water, shown in Fig. 126. The 2-inch pipe terminates slightly before the 8-inch pipe, and the feed water passes through the smaller pipe, and returns through the annular space between the two pipes along its former course to near its starting point, where, as shown by the arrows, it is discharged through slots into the boiler. By this means the feed water becomes heated practically to the same temperature as the water in the boiler before it mixes with the latter. In its course through the pipes, as it reaches 212° F., carbonic acid will be driven from the water, and the carbonates of lime and magnesia be liberated. When a temperature of 300° F. is attained, the sulphates will also be liberated. The water is reckoned to reach this temperature just after it emerges from the open end of the internal pipe; and as the outer pipe is larger the velocity of flow is correspondingly reduced, so that the annular space between the two pipes acts as a settling tank, in which the particles of lime and magnesia are deposited, along with any other impurity the water may contain, as the water slowly travels to its exit.

The removal of the accumulated deposit is effected by means of a blow-off tap in front of the boiler, as shown on the drawings. This is used at intervals, the interior of the apparatus scoured, and the deposit thus prevented turning to a hard scale. The apparatus can be applied to any existing boiler.

Boilers, for their proper preservation, should be placed under the periodical inspection of experts. An experienced inspector, skilled in the detection of the defects to which boilers of different types are liable, may detect early signs of deterioration, before an ordinary engineer would note anything amiss. These defects may then easily be remedied before much harm is done, and at a trifling cost. Any alterations that may from time to time become necessary or advisable, from the advancing age of boilers, such as a diminished working steam pressure, or unfitness for further work, will be reported by the expert.

Boilers are subject to explosion from a variety of causes. Defective material is a frequent cause. There may not be the necessary ductility or tensile strength in the plates, or the plates may have blisters in them.

Boiler plates whether of iron or steel are liable to blisters which are formed during the process of manufacture, but they proceed from different causes.

Those in the iron plates arise from pieces of slag or cinder getting between the layers whilst the manufacture proceeds. The slag is hammered and rolled with the iron, each process it goes through enlarging the superficial area over which it extends. Blisters weaken the plate, the weakening effect being greatest where the blister is thickest. They have been observed as large as 2 feet in diameter, and may be any smaller size. Where the piece of slag is

very small, its effect may only be to cause a lamination in the plate, but where of serious size the blister may attain a thickness of $\frac{1}{4}$ of an inch.

In manufacturing steel plates, all slag rises to the top of the ingot when the metal is in a molten state, the end afterwards being rough and uneven. The after treatment of the ingot consists in hammering and rolling, and results in intensifying the irregularity of the one end. Neglect to cut off this end and separate it from the rest, results in lamination in those plates made from the top end of the ingot. The lamination may not be suspected unless attention be called to it by cutting testing strips from it, or unless the plates require flanging in the boiler-shops. If the latter operation is resorted to the lamination is at once apparent, as there is then some difference in the position of the ends of the two pieces caused by the bending, as shown in Fig. 129, but the two portions of plates will always be in close contact with each other.

A defective safety-valve may cause an explosion; the valve may be overloaded, or out of order, or may stick in its seat.

Surcharged steam is another. This occurs when the water gets below the level of the flues, or where the flame by any means heats the brickwork above the water line causing a great addition to the temperature of the steam with little alteration of the indicated pressure.

Explosions have occurred where, while cleaning the boiler, wooden plugs have been driven into the branch, at the top of the boiler, common to both the stop-valve and the only safety-valve on the boiler. The plug has been driven in to prevent the entry of steam from other boilers of a range into the one requiring cleaning through a leaky stop-valve, and on re-starting the boiler, the plug has, through forgetfulness, not been removed. Consequently, as the steam is raised in the boiler and has no means of escape, on attaining sufficient pressure it bursts the boiler.

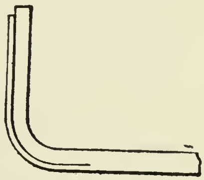


Fig. 129.—Laminated Steel Boiler Plate.

To guard against such occurrences, safety valve mountings should invariably be connected with separate and independent branches, and to guard against one being out of order, two should be placed on a boiler.

Accumulation of deposit is another possible cause of explosion. The impurity of the feed water produces this as already explained. The mineral salts in solution cannot pass away with the steam, and the water becomes so saturated that it deposits a portion as a crust on the inner surface. This deposit often takes the form of a hard scale and becomes firmly attached to the boiler plates. Owing to unequal expansion this scale may get separated from the plates, and the water then rushing in between them generates a considerable charge of highly elastic steam, which may result in an explosion.

Continual wear and tear may cause an explosion where boilers, too small for their work, are subjected to excessive firing resulting in injury to the plates. In time the boiler may be so weakened as to explode at the ordinary working pressure.

Deficiency of water is another cause of explosions. This may be brought about by negligence, or by relying on a single water-gauge which has got out of order.

However correctly a boiler may be seated, deficiency of water in the boiler causes the plates at the top of the side-flues, in Cornish and Lancashire boilers, to be exposed to the direct action of the fire, resulting in damage to the plates from the overheating and in the generation of steam at such pressure as may burst the boiler.

Fracture of plates and angle-irons produced by unequal expansion and contraction, causes explosions.

Corrosion, either internally from the impurity of the water supplied, or from the grease and oil sent into the boiler with feed-water which has been heated by exhaust-steam, or externally from leakages at the joints, may cause explosions, or the external corrosion may result from contact with damp brickwork at the seatings or elsewhere. The effect of corrosion is a wasting away of the plates, which become weaker and weaker as the corrosion continues. Internal corrosion follows no defined law. It may cause clear and well-defined pit-holes, or honey-combing more or less close in appearance, or a large extent of plate surface may be so evenly wasted as to defy detection unless the plates be drilled. Instances are recorded where corrosion has reduced the plates over the seating-walls to $\frac{1}{32}$ of an inch thick, and even less; if boilers, on examination, are found with such thin plates, it is easily seen how little force is necessary to rupture them.

Grooving, which has already been described, causes explosions.

Many boilers have doubtless exploded from old age.

Old second-hand boilers, bought cheap, which may have lain about and become rusted, are erected—very soon to prove an expensive bargain.

Badly-designed and ill-constructed boilers, even when made of good materials, cause explosions.

Collapsed flues frequently result from faulty construction, and explosions may follow from improperly fixed water-gauges or cocks, their position being too high or too low on the boiler.

The abuse which some boilers are subjected to when undergoing repairs may result in their explosion on being again set to work. A thoroughly well-designed and constructed boiler may be placed, for instance, in careless or ignorant hands for repair, or in those of a practical working boiler-maker whose practice is limited to making tight joints, he being unable to calculate the sizes of material necessary to resist strains or pressures. Again, in removing Galloway tubes from Galloway boilers, blank flanges are substituted instead of making some provision to replace the sustaining strength to the flue of which it was robbed, the result being a collapsed flue on re-starting. The various kinds of expansion-rings in the furnace-tubes get removed for repairs, and are replaced by flat belts which do not allow expansion and contraction to proceed. The gusset stays get removed from the flat ends of boilers so as to enable a leakage to be stopped, and nothing to compensate for the diminished strength is provided. A leaky plate in the shell may be removed, and one considerably thinner used in the repair, tending thereby to produce an explosion.

Injury to workmen engaged in cleaning boilers has often resulted from such dangerous practices as the following. To prevent annoyance from leaky stop-valves, whilst in the boilers, wooden plugs are sometimes driven into the holes of stop-valves, which are afterwards blown out and the attendant scalded to death. Again, with a group of boilers where the blow-off cocks are all connected with a common discharge-pipe, workmen have been known to open the blow-off cock of one boiler, whilst others were engaged cleaning the inside of the adjoining boiler; the consequence being that the steam and water passed from the one boiler to the other, scalding the men within it. No attempt should be made to plug holes during the cleaning of boilers, and some arrangement must be made whereby the water cannot be run from one boiler to another through the blow-off cocks.

Before cleaning, the boiler should always, where circumstances permit, be allowed to cool gradually. This may prevent accident, and also prevent the scum from adhering and baking to the plates, which frequently happens from blowing-off hot. In case it is impossible to allow time for gradual cooling, after the water has been run out, before breaking any joint about the boiler or removing the manhole cover, it should be carefully ascertained that all pressure has sub-

sided. The pressure-gauge should be consulted, the safety-valve lifted, and the gauge-taps opened.

An economical method of warming the surface-buildings about a colliery is by means of steam-pipes laid from the boilers through the buildings. The amount of steam passing may be regulated by a cock. The steam should not be used for any other purpose, such as driving an engine, for the passage of the steam through the buildings in the summer months would make the buildings unbearably hot. Where it can be applied it saves a considerable amount of trouble in attention to fires, grates, &c.

A few rules relating to boilers will now be given.

The material for boiler-plates, rivets or stays, should have a tensile strength of at least 20 tons per square inch for boilers intended to be worked at ordinary pressures up to 60 lbs., but should have more for higher pressures.

Rule to find the Load on a Safety-Valve.

$\frac{\text{Whole weight on valve}}{D^2 \times \cdot 7854}$ = pressure per square inch, and the whole weight = the weight of the ball × the leverage, or the ratio of the length between the fulcrum and the valve, to the whole length of the lever. Therefore to graduate a lever for any desired pressure we have $\frac{\text{area of valve} \times \text{pressure}}{\text{leverage}}$ = required weight of ball, and consequently for any lower pressure with the same ball the leverage will be $\frac{\text{area of valve} \times \text{pressure}}{\text{weight of ball.}}$ For strict accuracy the weight of the lever also requires to be taken into account, that is, its whole weight acting at half its length and reckoned as part of the ball.

Rule to fix the Area of the Valve.

Area of valve in inches = weight of water evaporated per hour × ·005. Two valves each having half the area given by the rule are preferable to one large one.

The weight of steam in lbs. discharged per square inch of opening per hour through the safety-valve is :—Absolute pressure × 50.

A Lancashire boiler evaporates, as a maximum, about 200 lbs. of water per hour per square foot of grate ; and a Cornish boiler, in which the ratio of heating surface to grate surface is less, a maximum evaporation of 150 lbs. per square foot of grate per hour. A Cornish boiler with a 3 feet 6 inch internal flue and a fire-grate 6 feet long would have 21 square feet of grate ; a Lancashire boiler with the same length of grate, but with two 2 feet 9 inch internal flues, would have 33 square feet of grate.

Molesworth gives the following rules for land boilers.

For each nominal horse-power a boiler requires,—

1 cubic foot of water per hour.
1 square yard of heating surface.
1 square foot of fire-grate surface.
1 cube yard capacity.
28 square inches flue area ; 18 inches over bridge.

For cylindrical double-flued boilers an approximate rule is, $\frac{\text{length} \times \text{diameter}}{6}$ = nominal horse-power.

Rules for Heating and Grate Surfaces.

G = Fire-grate surface in square feet.
H.P. = Number of nominal horse-power.
h = Heating surface in square yards.

$$\text{H.P.} = \sqrt{h\,\text{G}}.$$

$$h = \frac{\text{H.P.}^2}{\text{G}}$$

$$\text{G} = \frac{\text{H.P.}^2}{h}$$

The maximum safe working pressure for well-made boiler shells may be found by the following rules:—

Iron.

Single riveted

$$p = \frac{12{,}500 \times t}{d}$$

$$t = \frac{p \times d}{12{,}500}$$

$$d = \frac{12{,}500 \times t}{p}$$

Double riveted

$$p = \frac{15{,}600 \times t}{d}$$

$$t = \frac{p \times d}{15{,}600}$$

$$d = \frac{15{,}600 \times t}{p}$$

where p = the pressure of steam in the boiler, t the thickness of plate in inches, and d the diameter of the shell in inches. For exceptionally riveted joints it will be better to take 5 tons as the working strength of the plate, and then by reference to the table given, the proportion of strength of joint to the solid plate can be calculated.

A steel boiler may be worked up to $\frac{1}{5}$th higher pressure than an iron boiler, and the following rules will apply for—

Steel.

Single riveted

$$p = \frac{15{,}000 \times t}{d}$$

$$t = \frac{p \times d}{15{,}000}$$

$$d = \frac{15{,}000 \times t}{p}$$

Double riveted

$$p = \frac{18{,}750 \times t}{d}$$

$$t = \frac{p \times d}{18{,}750}$$

$$d = \frac{18{,}750 \times t}{p}$$

Frequently the tensile strength of good boiler plates of iron is taken at 21 tons per square inch of section, and the working pressure of a boiler ascertained by

assuming a factor of safety of 6. By some it is considered that the factor of safety should not be much higher than 4; that 6 is too high and does not agree with the practice of the Insurance Companies, whilst the above rules do. The pressures must however be regarded as a maximum, not to be exceeded.

Suppose it is required to find the thickness of iron plate necessary for a Lancashire boiler 7 feet 6 inches diameter which is required to work at a pressure of 70 lbs. per square inch. The longitudinal seams are to be lap joints double riveted.

$$\text{Here } t = \frac{70 \times 90}{15{,}600} = {\cdot}41 \text{ of an inch.}$$

If the tensile strength be taken at 21 tons, $21 \times 2{,}240 = 47{,}040$ lbs., and a reference to the table shows the joint to have 69 per cent. of the solid plate if the holes have been punched ∴ the tensile strength of the joint is $47{,}040 \text{ lbs.} \times {\cdot}69 = 32{,}457{\cdot}6$ lbs. per square inch.

Taking the factor of safety of 6, the bursting pressure must be $70 \times 6 = 420$ lbs. per square inch.

$$\text{Then } t = \frac{p \times d}{2 \times 32{,}457{\cdot}6} = \frac{420 \times 90}{64{,}915{\cdot}2} = {\cdot}58 \text{ of an inch.}$$

A simple approximate rule for ascertaining the strength of a well-made boiler is to remember that for a 7 feet double riveted shell of wrought iron, each $\frac{1}{16}$ inch plate thickness, is equivalent to 10 lbs. pressure fully. Thus, for a $\frac{7}{16}$ inch plate we get 70 lbs. boiler. For other diameters and other materials make due allowances.

To determine the number of boilers required at a colliery, allow one 7 feet 6 inches diameter 28 feet long Lancashire boiler for every 200 horse-power exerted by the engines, and then add an extra boiler to the range to permit of one being laid off for repair.

A boiler of 20 horse-power is usually 15 feet long and 6 feet wide, therefore 90 feet of surface or $4\frac{1}{2}$ feet to 1 horse-power; a boiler of 14 horse-power 60 feet of surface or $4{\cdot}3$ feet to 1 horse-power, but engineers allow 5 feet of surface to 1 horse-power.

The steam pipes must be suitable in size to the cylinders of the engine they supply with steam. The proper way to determine their size is by considering the velocity of the steam through them. Mr. Tredgold says, the force of steam in the boiler multiplied by the velocity and the area of the passage must be equal to the elastic force on the piston multiplied by its area and velocity. That is

$$a.f.v. = \text{A V} p.$$

where a = area of the steam passages.
f = the force of steam in the boiler in inches of mercury.
v = the velocity of steam through the pipes.
p = the force of the piston in the same denomination as f.
A = the area of the piston.
V = the velocity of the piston.

$$\therefore v = \frac{\text{A V} p}{a.f}$$

$$\text{or } a = \frac{\text{A V} p}{f.v}.$$

The pressure of the steam in the boilers exceeds the pressure in the cylinders in a ratio which varies from $1\frac{1}{12}$ to double in different engines, and for general

calculations is taken at $1\frac{1}{2}$ times. Thus a boiler pressure of 60 lbs. would be equal to 40 lbs. pressure in the cylinders, the difference being employed to overcome the resistance of the steam pipes, valve ports, &c.

The size of the steam pipe should be such that the velocity of the steam flowing through it shall not exceed 100 feet per second.

Molesworth gives the following as the average evaporative power of fuel:—

1 lb. of coke evaporates 9 lbs. of water.*
1 „ „ coal „ 9 „ „ „
1 „ „ coal (slack) „ 4 „ „ „

Stationary expansive condensing engines use from 4 to 7 lbs. of coal per indicated horse-power per hour. Compound engines, $1\frac{3}{4}$ to 3 lbs.

As supplementary to the foregoing, a few questions and answers relating to boilers will now be given.

Question 26.—Describe fully separators and steam-traps and their use.

Separators are arrangements for draining the water out of long ranges of steam-pipes, which is formed there either by "priming," that is carried from the boiler with the steam into the pipes, or by condensation. The under part of the separator is below the level of the steam-pipes, and it is formed so that the water and steam, in passing from the steam-pipes into the separator, are effectually separated there, hence the name. The water is precipitated to the bottom of the vessel called the separator, whilst the steam is made to pass upward round a deflector and enters the steam pipe on the other side quite dry.

A steam trap is an appliance for automatically freeing from condensed water all steam passages and pipes in which such water may have accumulated. This water, when allowed to remain in, occasions considerable leakage and damage, as well as wear and oxidation arising from the water which remains in the passages while the engine is standing. It is sometimes applied direct to the lowest level of the steam pipes so that all water may flow to it; in other forms it is attached to the separator, which it automatically frees of the water accumulated there. There are many different steam traps before the public. The following sketch, Fig. 130, and description of MM. Geneste and Hercher's Self-acting Steam Trap, are taken from the *Colliery Guardian* of April 16th, 1875.

Two cylinders, C and D, of the same weight, but of different densities, are arranged at the two ends of a rod which is free to oscillate on a shaft at right angles to it. This shaft carries a toothed pinion which gears with a rack, at the end of which is fixed a slide valve, E, serving to open an escape orifice, B. If the apparatus is connected by means of the pipe, A, to the steam pipe which it is intended to keep clear of water, the water and the steam enter this first-mentioned pipe. As the two cylinders in equilibrium are of the same weight but of different densities, it is evident that their volumes differ in inverse proportion to their densities; the result is that the condensed water, which will be accumulated in the lower portion of the trap, will in time rise to one or both of the cylinders; the volumes of water displaced being different, the equilibrium will be disturbed, and the oscillation which will result will bring about the opening of the slide-valve, E. The water will thus be at liberty to flow away, and it is easy to conceive that the slide valve will be opened in proportion to the quantity of water to be ejected. It is claimed for this trap that it is applicable for removing water in passages for compressed air.

Tangye's Self-acting Steam Trap and Separator, which, correctly speaking, is a condensed-steam trap, is an automatic apparatus for separating and afterwards discharging the water resulting from the condensation of steam in pipes,

* Feed-water supplied at 212° F.

steam chests, receivers, drying apparatus, &c. It is made by the well-known firm of engineers, Messrs. Tangyes, Limited, of Birmingham.

As will be seen by Fig. 131, it is exceedingly simple in construction, having few working parts, and therefore not liable to get out of order, and can be easily applied by fixing in a line of pipes to which it is joined at the branches cast with the top vessel of separator.

The separator consists of a cast-iron cylinder with a perforated bottom, and divided vertically into two chambers by a partition, and provided with a cover at the top, in which is fixed a small valve, opening inwards, by which air is discharged when first turning on the steam, or to admit air when the steam is turned off. By means of the partition, the steam and water from the pipes are made to pass from one chamber down through the perforations when the water falling is trapped, while the lighter steam, rising through the holes into the opposite chamber, proceeds onwards freed from water.

The bottom casing in which the water is trapped, and from which it is afterwards expelled, consists of a cast-iron cylinder, having a solid bottom, to the top of which

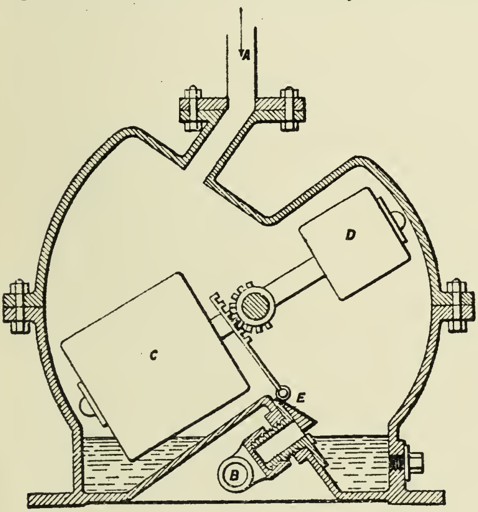


Fig. 130.—MM. Geneste and Hercher's Self-acting Steam-trap.

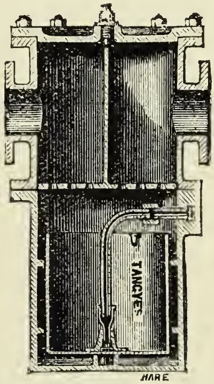


Fig. 131.—Tangye's Self-acting Steam-trap and Separator.

is bolted the separator—a small iron cistern cast of such a thickness that it will float in water by displacement, and a bent pipe secured to an outlet at the side of casing, and extending therefrom over the side and down the centre, nearly to the bottom, of the cistern, and terminating with a brass nozzle, having a flat valve face at its extremity. The cistern is provided with a small brass disc valve, which is rounded on its underside, so that it shall readily adjust itself to the seat on the nozzle, and is kept in position by a guard.

The action is as follows:—Suppose the casing with cistern to be filled with water, the cistern with its valve will immediately sink to the bottom of casing by the force of gravity, and thus open communication with the atmosphere, through the bent pipe, where the steam pressing on the surface of the water will discharge the cistern of so much of its contents until the weight of the remainder, together with that of the cistern, are overbalanced by the surrounding water.

The cistern will then rise, carrying with it the small valve, and thus close the passage through the bent pipe, and remain in that position until the accumulation of water from condensation again fills the cistern, when the operation will be repeated.

Recently, Mr. John J. Royle, of Manchester, has devised a steam trap by means of which the condensed water may be returned automatically to the boiler. It is shown at Fig. 132. A is a steam chest on the top of the receiver B, having a three-port slide valve C—of which the port D communicates with the receiver B —the port E communicates, through a pipe not shown, with the drip box, not shown, and the port H with the atmosphere. The slide valve C is actuated by pistons I and J, working in open-ended cylinders affixed at each end of the steam chest A, as illustrated. The closed ends of the cylinder communicate, the one through the bent pipe with the inside of the receiver B through a valve actuated by the float M, and the other through a pipe communicating with the drip box through a valve also actuated by a float.

The fixing of the apparatus will be readily understood from Fig. 132, where the receiver B is shown fixed above, and arranged to feed back the condensed water to the boiler coming from a system of heating pipes and coils all draining into the drip box situated considerably below the boiler. Steam at the full boiler pressure is supplied through a pipe to the steam chest A, and entering through the open port D presses upon the water S shown in the receiver B, and establishes an equilibrium between the boiler and the receiver, allowing the water to gravitate through check valve T and pipe continued from it to the boiler. Meanwhile the condensed water from the heating pipes, &c., has been entering the drip box through a check valve, and as soon as the water in the drip box reaches the ball of float and lifts the valve connected with it, the equilibrium of the pistons I and J is destroyed and the slide-valve C caused to travel to the right, so reversing the position of the ports, admitting steam at boiler pressure through the pipe leading into the drip box, and allowing the steam contained in the receiver B to exhaust. The condensed water in the drip box is by this means forced up another pipe and through check valve X into the receiver B, until, as soon as it in turn reaches the float M, the slide-valve C is automatically moved to the left into its former position, so admitting full steam pressure on to the water S and feeding it to the boiler as before described.

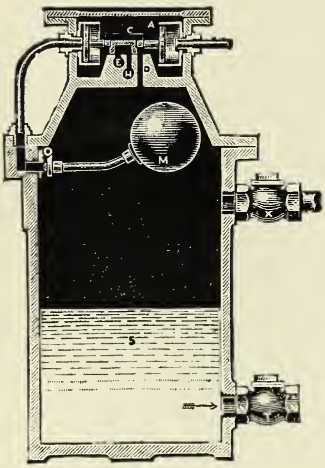


Fig. 132.—Royle's Automatic Return Steam-trap.

Meanwhile the condensed water accumulates in the drip box, and as soon as it again lifts the ball of float there, the same action is repeated, and so on continuously.

The special features claimed for this steam trap are:—1. It will automatically elevate boiling water from any distance below the boiler, and feed it into the boiler against any pressure, without requiring any back pressure on the drip pipes—a feature unique, and possessed by no other return trap. 2. Heating pipes can therefore be worked at any steam pressure, and at any distance above or below the boiler. 3. As a boiler feeder this apparatus possesses special advantages for feeding boiling water lying either above or below the boiler level, and which would be impossible to feed back to the boiler by other means.

In the "Expandisc" Steam Trap shown in Figs. 133 and 134; 133 is an exterior view, while 134 is a sectional one. In it advantage is taken of the

quality which certain alloys of metal possess of expansion and contraction under varying temperatures.

The steam trap consists of a cast-iron cylindrical casing—$17\frac{1}{2}$ inches high and 10 inches diameter at the base—in the centre of which is a brass valve spindle, carrying four circular valve discs, all cast in one piece from a specially expansive alloy. The casing is bored out conically and the discs are turned conically. They can be raised and lowered by means of a hand wheel and screw working in a bush screwed inside and outside.

The air and condensed water enter the steam trap at the top. Their temperature being lower than that of steam causes the conical discs to contract. This contraction leaves an annular space between the circumference of the discs and the interior surface of the casing, sufficient for the outflow of the water. When there is no more air or water the steam comes in contact with the discs, expands them and thus closes the annular space, thereby preventing the steam from escaping. As soon as water again accumulates in the trap, the contraction of the discs takes place, the water escapes, and the incoming steam raises the temperature, expands the discs and closes the trap.

These expansions and contractions alternate automatically, according as steam

Fig. 133.

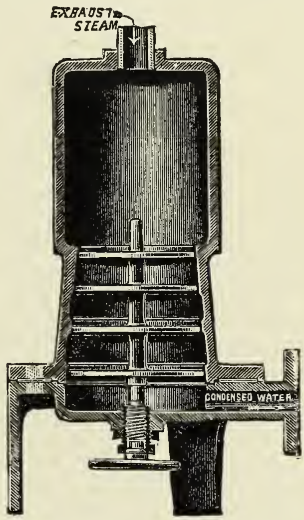


Fig. 134.

The Expandisc Steam-trap.

or water is present, and the efficiency of the steam trap is based on the power which the special alloy has of expanding and contracting.

The desired position of the discs is attained by screwing up the bottom bush by means of the key furnished with each trap. This position is easily regulated according to the outflow. The discs must be raised until only water flows, and when once regulated no further adjustment is required.

The valve spindle and discs are lowered by means of the screw and hand-wheel. The steam is allowed to escape for one or two minutes through the annular passage thus formed, and sweeps away any impurities which may have settled on the interior of the casing or on the discs. The valve spindle is then raised to its former adjusted position.

Extreme height......	$17\frac{1}{2}$ inches.	Inlet......	$1\frac{1}{4}$ inches diameter.
Diameter at base ...	10 inches.	Outlet ...	$\frac{3}{4}$ inch diameter.

Question 27.—What are feed-water heaters and economisers?

A feed-water heater is simply an appliance for heating the feed water by means of exhaust steam, before passing into the boiler. There is manifestly an advantage in sending the feed water to the boilers hot, and at collieries there is usually much exhaust steam that may be utilised for the purpose. In its simplest form the feed-water heater consists of an old boiler, into which the exhaust is conveyed below, and the feed water is conveyed above. The exhaust steam is condensed on coming into contact with the cold water, and the temperature of the feed water is thereby raised. This is then conveyed to the boilers by another pipe. This plan frequently requires the use of two pumps, one for the hot and one for the cold water, and whatever impurities come from the cylinders go into the boiler and from the boiler into the cylinder again. By the use of Berryman's feed-water heater, or others of that description, the evil of passing the grease and dirt from the cylinders into the boiler is avoided. The exhaust steam enters the heater and passes through a number of brass and copper tubes, which are surrounded by the cold feed which enters the heater at another point. The passage of the steam through the tubes raises the temperature of the feed water, which is conveyed by a pipe from the heater for the purpose to the boilers. The exhaust steam does not mix with the feed water, but passes out of the heater by a proper outlet. Only one pump is required for the cold water, or an injector may be used. The Berryman heater is also used as an interheater where compound engines are working. It may be fixed at any convenient distance from the cylinders in or outside the engine-room. The exhaust steam is passed through the inside of the tubes in the interheater and thence into the steam chest of the low pressure cylinder. The objection to these heaters are their tubes and complications which are liable to get out of order, and probably the best feed-water heater is the exhaust injector, which has been fully described. In it there are no tubes to get out of order; it requires no pump, is simple in construction, and effectually heats the feed water being conveyed to the boilers. An economiser is somewhat similar to a feed-water heater, but in it the water is heated by the hot gases which issue from the boiler flues. These gases pass through the tubes similarly to the exhaust steam in the feed-water heater.

Question 28.—Besides the ordinary lever safety valve, describe any other safety arrangements that have been devised for boilers.

Cowburn's dead-weighted safety valves are stated to be much more efficient than the ordinary lever valve. They are made singly or in groups. Each valve in a group is exactly one square inch area and the heap of weights is just the intended pressure in pounds. These weights keep the valve in its seat until the steam attains a certain pressure, when the steam lifts the valve and escapes through the opening at the top of the weights.

Johnston's patent self-acting alarm whistle guards against accidents from deficiency of water in the boiler. A hollow cast-iron float is made sufficiently heavy that on falling with the water in the boiler it opens an orifice through which the steam rushes, thereby causing the alarm whistle at the top to be sounded. The apparatus is free of all stuffing boxes, glands, cocks, or any complicated contrivances. As long as there is sufficient water in the boiler, the alarm valve is kept close against its seat by the float.

Smith's steam sentinel is an invention to prevent over-pressure in steam boilers, and is a check on the safety valve, because it gives a distinct and unmistakable warning immediately the maximum pressure is exceeded. Its construction is simple. A conical valve stops a hole in the boiler, and is kept down by a spring

carefully adjusted to resist the pressure of the steam up to a certain point. As soon as this pressure is exceeded, the valve is liberated by the compression of the spring, and a communication is opened for the steam into a whistle of the ordinary form, which gives a loud warning of approaching danger.

Question 29.—In a lever safety valve, the whole length of the lever is 32 inches, the distance between the fulcrum and the valve 4 inches, the diameter of the valve $2\frac{1}{2}$ inches, required what weight must be put on at the end of the lever so as to have a pressure of 50 lbs. per square inch upon the valve; also to divide the lever so as to have 40, 30, and 20 lbs. upon the valve with the same weight?

The area of the valve will be $2{\cdot}5^2 \times {\cdot}7854 = 4{\cdot}9$.

The leverage will be $\frac{32}{4} = 8$, so for a 50-lb. pressure we have $\frac{4{\cdot}9 \times 50}{8} =$ $30\frac{5}{8}$ lbs. as the weight to be put on the end of the lever to give 50 lbs. per square inch. And $\frac{4{\cdot}9 \times 40}{30\frac{5}{8}} = 6{\cdot}4$; and $6{\cdot}4 \times 4 = 25{\cdot}6$ inches, the distance from the fulcrum at which the weight must be put to have a pressure on the valve of 40 lbs. Similarly $\frac{4{\cdot}9 \times 30}{30\frac{5}{8}} = 4{\cdot}8$ and $4{\cdot}8 \times 4 = 19{\cdot}2$ inches, the distance from the fulcrum at which the weight must be put to have a pressure on the valve of 30 lbs. Again, $\frac{4{\cdot}9 \times 20}{30\frac{5}{8}} = 3{\cdot}2$ and $3{\cdot}2 \times 4 = 12{\cdot}8$ inches, the distance from the fulcrum the weight must be put to have a pressure on the valve of 20 lbs. The weight, it will be thus seen, must be moved towards the fulcrum ($32 - 25{\cdot}6$) $6{\cdot}4$ inches for every 10 lbs. taken off the pressure on the valve.

Question 30.—What is the pressure per square inch in a boiler, the whole length of the lever being 32 inches, the distance between the fulcrum and valve 4 inches, the diameter of the valve being $2\frac{1}{2}$ inches, a weight of $30\frac{5}{8}$ lbs. being placed at the end of the lever?

Here we have $\frac{32}{4} = 8$ for the leverage, therefore the whole weight on the valve is $30\frac{5}{8} \times 8 = 245$ lbs., and $\frac{245}{2{\cdot}5^2 \times {\cdot}7854} = 50$ lbs. as the pressure per square inch in the boiler.

Question 31.—If the safety valve is $4\frac{3}{4}$ inches in diameter, and the lever is 38 inches long to the centre of the weight, and $4\frac{1}{2}$ inches from the fulcrum to the centre of the valve, and the weight is 85 lbs., what is the pressure per square inch?

The leverage is $\frac{38}{4\frac{1}{2}} = 8{\cdot}\dot{4}$, and $8{\cdot}\dot{4} \times 85 = 718$ lbs. nearly. The area of the valve would be $4{\cdot}75^2 \times {\cdot}7854 = 17{\cdot}72$ square inches. Therefore $\frac{718}{17{\cdot}72} = 40\frac{1}{2}$ lbs. per square inch.

Question 32.—A steam gauge shows 20 lbs. on its face, what does this mean?

As already explained, that the pressure of the steam inside the boiler is 20 lbs. above the pressure of the atmosphere.

Question 33.—What is the effect of sediment or incrustation forming in a boiler? Is there any danger likely to arise from it?

The deposits or incrustations formed internally on the boiler plates are salts, and bad conductors of heat. Consequently, the boiler plates will become red hot whilst the deposit remains; after becoming red hot, through unequal expansion, the incrustation separates from the iron, the consequence being that water rushes between, a sudden generation of highly elastic steam takes place, which sometimes the valve will not allow to pass, and an explosion follows.

Question 34.—Are boiler plates ever made less than $\frac{5}{16}$ of an inch thick? What is the proper size and strength of plates for high-pressure boilers?

Boiler plates are not often made less than $\frac{5}{16}$ of an inch thick. For high-pressure boilers, they are made from $\frac{7}{16}$ to $\frac{11}{16}$ of an inch thick, and are commonly 6 feet × 3 feet, and they must have a tensile strength of at least 20 tons to the square inch. Steel plates are now rolled large enough to admit of one plate forming an entire ring. Thus there is only one longitudinal seam in the boiler made of such plates.

Question 35.—What evaporating surface should boilers have?

They should have at least 5 square feet per horse power.

Question 36.—When the water in a boiler is dangerously low, what would you do?

I should open the fire-doors, close the damper, and stand at a safe distance until the boiler had got cool, and for this reason. If the water is allowed to get dangerously low, some of the plates will be subjected to great heat—possibly may be red hot—and any attempt to pass water into the boiler while in that state would be followed by a rapid generation of highly elastic steam, which the safety valve would not pass, and an explosion would result. After the boiler had cooled, it might safely be re-filled and started.

Question 37.—At what part of the boiler would you fix the water gauge?

The water gauge should be placed on the front and furnace end of the boiler, where it would be constantly under the eye of the fireman, and any deficiency or surplus of water in the boiler at once detected.

Question 38.—What size of steam pipe would you lay from the receiver to a 30-inch cylinder engine?

The maximum velocity of the steam in the main steam pipe should not exceed 100 feet per second. The piston speed of the engine is not given, but taking it at 300 feet per minute, the size of pipe for a single cylinder engine would be found thus:—A 30-inch diameter cylinder has an area of 706·86, therefore $\frac{300 \times 706{\cdot}86}{100 \times 60} = 35{\cdot}343$ area in inches, and $\sqrt{\frac{35{\cdot}343}{{\cdot}7854}} = 6{\cdot}7$ inches, or say $6\frac{3}{4}$ inches in diameter. With a double-cylindered engine it would be $\frac{300 \times 706{\cdot}86 \times 2}{100 \times 60}$ $= 70{\cdot}686$ area in inches, and $\sqrt{\frac{70{\cdot}686}{{\cdot}7854}} = 9{\cdot}487$ inches, or say $9\frac{1}{2}$ inches in diameter. If the engine is a compound one, only the size of the high-pressure cylinder need be considered in estimating the size of the steam pipe.

Question 39.—In a colliery where engines were working, and having 1,800 horse-power, what boilers would you consider necessary?

$\frac{1800}{200} = 9 + 1 = 10$ Lancashire boilers 28 feet long and 7 feet 6 inches diameter.

Question 40.—What height and size of chimney would you construct for such range of boilers?

$10 \times 5 = 50$ feet area = say 8 feet diameter at the base, and to be well proportioned the chimney should be 25 times the diameter in height $= 8 \times 25 = 200$ feet high.

Question 41.—What is the nominal horse-power of a Lancashire boiler whose length is 30 feet and diameter 6 feet?

$\frac{30 \times 6}{6} = 30$ horse-power.

Question 42.—Are boilers better calculated to resist pressure lengthwise or crosswise, and in what proportion?

A common cylindrical boiler is twice as strong to resist pressures acting lengthwise than to resist pressures crosswise, and for this reason all the horizontal seams should be double riveted.

Question 43.—How much stronger are boilers having double-riveted plates than those having single-riveted plates?

Double riveting weakens the plates about one-fourth, single riveting about one-half, therefore double-riveted boilers are stronger in the proportion of about 3 to 2.

Question 44.—Find the bursting strength of an iron cylindrical boiler 6 feet in diameter, and made of ½-inch plates, with doubled-riveted joints.

$$\frac{\cdot 5 \times 21 \times 2240 \times \cdot 69}{6 \times 12} = 225 \cdot 4 \text{ lbs. per square inch.}$$

At most collieries railways are required, but the circumstances of each must decide what railways shall be made. Siding room for full and empty trucks sufficient for the day will be required, but in laying out, regard will of course be had to the intervals between the trains and the output of the colliery. It is not necessary to say more of this here, nor is it necessary to explain the different forms of wagon in use, as these vary much in different districts. Coke ovens and coal-washing machinery, briquette and brick-making machines are in use in some districts, and form part of the surface arrangements; but as these subjects are adjuncts to mining, and a knowledge of them not absolutely necessary for a student to pass an examination in mining, it is not necessary that they should be treated here.

At collieries which supply gunpowder or other explosives, it will be necessary to remember the provisions of the Explosives Act, and to erect the gunpowder magazine in accordance with legal requirements. The written approval of H.M. Inspector should always be obtained both as to plans and position before erection.

A ventilating-fan and a pumping-engine may also possibly form part of the surface erections, but more will be said of these under the heads of Ventilation and Drainage.

CHAPTER VI.

TIMBERING AND WALLING.

The kind of Timber used at Collieries—Storing it Underground—Method of fixing Props and Lids—Temporary Props and Lids—"Dog" for drawing Props—"Sets" of Timber and their fixing in Main Roadways—Timber for Collars—Sills under Props—Timbering for a bad Roof, where the Floor and Sides are good—Lagging—Timbering for a bad Roof and Side, the other Side and Floor being good—Timbering for a bad Roof and Sides, with a good Floor—Timbering for a bad Roof, Floor and Sides—Lagging of Trees and Brushwood—Sizes of Timbers and their distance apart—"Cogs" or "Chocks"—Methods of Timbering in France—Notching the Timber—Cast-Iron Props—Wrought-Iron and Steel Supports—Storing the Timber on the surface—Creosoting as a means of preserving Timber from decay—Customs as to Setting and Drawing the Timber—Walling the Main Roads from the Shaft—Material used in Walling—Semi-circular arched Roadway—Invert under Side Walls—"Horse-shoe" Arch—Elliptical Arch for Roadway—Process of building Arches—Necessity of removing all Timber, and tightly packing behind the Walls of Arches—Packing the Top and Sides with Sand.

TIMBERING is the cheapest way of securing roads, regard being had to first cost only; but if the roads are used a number of years, and the cost of maintenance is taken into account, walling may be a much better and cheaper plan.

The timber used at collieries to support the roof and sides is chiefly pine, fir, and oak. The sizes vary from 4 to 12 inches in diameter, the size and arrangement depending upon the material to be supported and the excavation itself. Where used to support the roof only, the timber requires very little preparation. It is cut into suitable lengths at the surface, sent into the pit, and, in accordance with the Mines Act, 1887, for the convenience of the workmen who have to timber the working places, a proper supply must be kept stored near at hand.

The usual manner of supporting the roof in the working places is by means of single props (called posts, trees, &c.), having short lids or caps (in Somersetshire called traps) on the top. If these props are cut from the tops of old trees, they are spongy in texture, and less durable than when cut from the lower portions of young trees. The bark should always be left on them, as it helps to preserve the wood.

In fixing props, the workman with one hand holds the lid under the roof requiring support, whilst with the other he moves the top of the prop, the bottom of which rests on the floor, until it touches the lid, which is firmly held by the post, while the latter is driven well under the lid by means of a sledge-hammer. The post should be upright if the seam lies flat; if not, the prop will not be upright, but at right angles to the floor and roof, or, as the roof will sink a little, notwithstanding the prop, the latter may be set in a direction which deviates slightly from the perpendicular between floor and roof towards the vertical. A single prop and lid is sometimes though not often fixed in the main roadways as well as the working places. Fig. 135 shows a single prop and lid. At times it is required to fix a single prop and lid for a temporary or passing purpose.

For instance, where a double row of "chocks" is used in Longwall workings, as a protection to a continually advancing face, the back row is often taken down and re-fixed in front of that which was previously the front row. Each of these chocks

should have temporary single props and lids, placed round it to protect the workman while in the act of taking out the chocks. These temporary single props may afterwards be withdrawn, and to facilitate the after removal, when fixing them a short sill is placed on a few inches of rubbish, the prop and lid being placed over the sill (see Fig. 136). These props are afterwards safely removed and recovered by means of a "dog." Fig. 137 shows a "dog" for drawing props, as

Scale. 6 Feet to 1 Inch

Fig. 135.

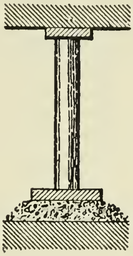


Fig. 136.

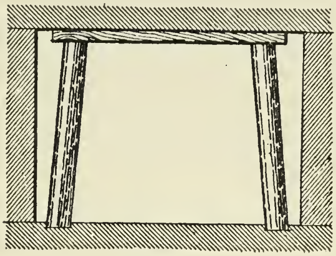


Fig. 138.

METHODS OF TIMBERING ROADWAYS.

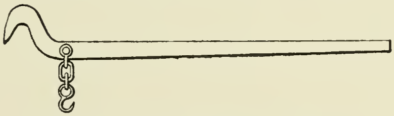


Fig. 137.—DOG FOR DRAWING PROPS.

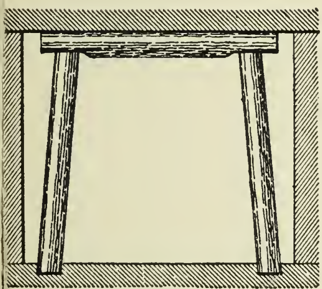


Fig. 141.

Fig. 142.

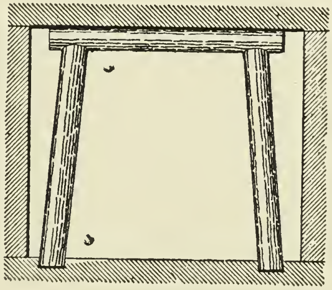


Fig. 143.

Fig. 144.

METHODS OF TIMBERING ROADWAYS.

used at the Lundhill Colliery, Yorkshire. It is an iron bar 3 feet long, with one end shaped in the form of a hook, as shown in the sketch. Five inches from the hook end is a chain with two links and a hook about 6 inches long. The "dog" is used with a piece of half-inch long-linked chain 6 feet or more in length, with a hook at the end of it. The chain is passed round the prop to be drawn, and hooked into a link. The other end of the chain is put into the hook at the end of the "dog" chain. Another prop is used as a fulcrum, the point of the lever is pressed against this, and the prop is drawn out. The length of the chain must be such as to allow the timber-drawer to be safely clear of the falling roof consequent on the withdrawal of the post.

Usually the main roadways are secured by "pairs" or "sets" of timbers, as shown at Figs. 138, 141, 142, 143 and 144, Figs. 138, 141 and 143 being front elevations, and Figs. 142 and 144 side elevations of roadway. These consist of a

head-piece or "collar," which is held up in position next the roof by two props, reaching from the floor to near each end of the "collar."

It requires two timbermen in large roadways to fix this timber, and if the roof is very bad it may require more.

The collar, having been placed where required, is held there temporarily by a prop from the floor to the middle of the collar. Holes or notches are prepared beforehand in the floor at the sides of the road. One end of a prop is now placed in one of these notches, and the other is brought under the collar, where it is driven sufficiently to be quite firm. The other prop is treated similarly, and the two props may afterwards be alternately tightened by being more firmly driven under the collar, after which the middle prop is removed. As seen on the drawings, these props instead of being vertical when in position are slightly inclined at the top towards the centre of the roadway. The object of this is to strengthen the support. The distance of these props from each other on the floor of the road is often regulated by the gauge of the way and the size of tub or tram having to pass between them; if made the same distance apart at the top and bottom, the weight of the incumbent strata would be more likely to break the collar in the centre than when the props are slightly inclined towards each other at the top, thereby reducing the length of collar between the supports.

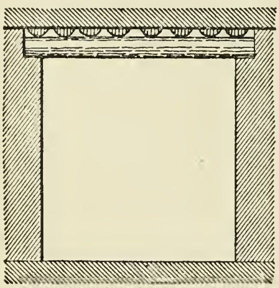


Fig. 139.—Timbering a Roadway.

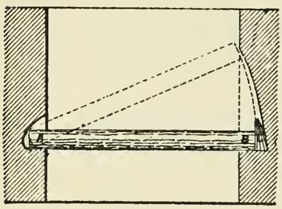


Fig. 140.—Timbering a Roadway.

Sometimes the "collars" consist of slabs of wood or "flats" sawn into suitable lengths, as shown in Fig. 138, but as this kind of collar will not bear much weight without breaking, more frequently trees with the bark left on exactly the same as the props are used. In other cases they are split down the middle, so as to form two half-round pieces, and where this is so the splitting should be done by cleavage, because sawing slightly weakens the piece by dividing the fibres. Where space is not important, however, it may be found more economical to select slightly larger timbers and saw them, the larger size compensating for the loss of strength resulting from sawing. Where these half-round pieces are used as "collars," the flat portion should be laid next the roof, in order to cover as large a surface as possible. Whatever the collar is, care must be taken to ensure its bearing against the roof.

If the latter has an even surface, there will not be much difficulty in this, but in other cases the irregularity of the roof presents obstacles to true contact between it and the collar.

In fixing the props which support the collars, they are placed sometimes with the smaller ends downwards, and sometimes with the smaller ends upwards, but if the floor is strong the smaller ends should be downwards.

If the floor is very soft, the pressure from above causes the props to sink, and the larger ends should be downwards. In some cases this will not be sufficient to prevent the sinking, and advantage may be derived from placing a sill under the foot of each prop. The size of sill will be determined by experience.

Roadways having a strong floor and sides, but a bad roof, do not require the "sets" of timber just described. In these no props will be required, as the sides of the roadways are notched sufficiently for the insertion of the collars, which thus

rest or have a bearing on the sides. Fig. 139 shows the front elevation of a roadway timbered in this way, and Fig. 140 shows a plan of the same. A hole or notch is prepared in the side A, near the roof, and is cut to a depth sufficient to give the bearing it is requisite the collar should have. On the opposite side of the roadway, and at the same height, is cut a similar hole B, but the fore side of the hole is shorn away, as shown in the figure, to allow for the fixing of the collar. One end of the collar is now placed at A, the collar being held in the position shown by the dotted lines in the figure, whilst doing so. As the end B approaches its permanent position, a wedge is placed at C, having its thin end outwards, as shown in the figure, and against this wedge the collar is driven home by blows from a heavy hammer. If the road is steep, the shearing back for the hole B should be on the higher side, as the collar would be thus less liable to work out after fixing.

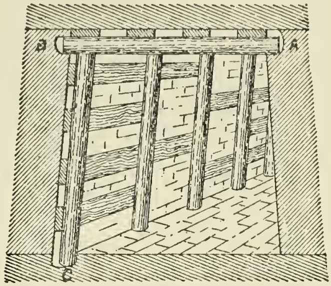


Fig. 145.—Timbering a Roadway.

If the collars are not sufficient to prevent falls from the roof, lagging is placed in between the collars and the roof at right angles to the collars. The lagging may be of slabs, or round or half-round timber. If half-round be used, the flat side should be placed next the roof, as shown in Fig. 139. The object of either kind of lagging is to distribute the support of the collars over the roof. If after placing the lagging over the collars, any spaces exist, either between the collars and lagging or between the lagging and roof, these should be closed by having wedges firmly driven into them.

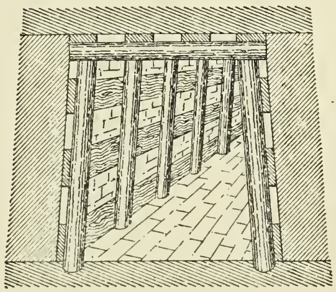


Fig. 146.—Timbering a Roadway.

If a roadway has a bad roof and side, the other side and floor being good, it may be "half timbered," as shown in Fig. 145. A hole is cut in the sound side at A to receive one end of the collar and the floor is notched at C, in which is fixed a prop, slightly inclined. A collar is then placed with one end in the notch A and the other resting on the prop. The prop and collar are now driven by blows till the former is quite upright or slightly inclined towards the centre of the road. If the two pieces are not held firmly together, owing to the yielding of the floor during the driving, wedges are driven either above or below the prop.

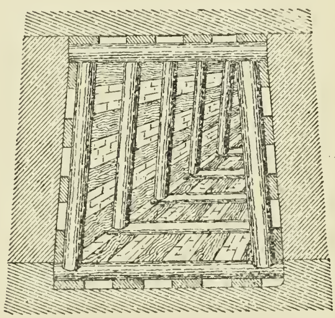


Fig. 147.—Timbering a Roadway

Lagging is placed next the roof and also next the side from which the pressure is threatened. The lagging between the props and the side is firmly wedged so as to retain its proper position.

Fig. 146 shows the timbering in a roadway having a bad roof and sides, but a

good floor. Here "sets" of timbers are placed as before described, and lagging placed next the roof and against both sides. Flat, half round, or round lagging may be used, according to the pressure it is likely to have to resist, vertically, or laterally.

It often happens that the roof, floor and sides are all weak and require support. Where this is the case, if the roadway is to be maintained for any length of time, walling will be the most effectual and economical way of preserving the road. But if only required for a short time, it may be timbered as shown in Fig. 147. In this case, the "sets" of timber have placed under them pieces similar to the collars, and these may be of half-round pieces if the pressure is not great. Where the half-round pieces are not strong enough, whole pieces must be used; and again, where these do not effectually resist the pressure, lagging must be placed under them, similar to the lagging at the sides and roof as shown in Fig. 147.

In the southern portion of the Somerset coalfield, and also in some of the Pembrokeshire mines, where the roads are very difficult to keep open, branches of trees and brushwood are frequently used as lagging. These form a network against the sides and roof and distribute the weight more evenly over the supports than ordinary lagging.

The distance between the sets of timber or the collars must depend upon the state of the strata. In some cases they may be placed only a few inches apart, the road being quite lined with them, or in others at intervals of 3 feet or upwards.

Where the timbers are not of a uniform size along a roadway, the larger and smaller should be made to alternate, so that a weak pair may come between two strong ones, but this method is not desirable.

The diameters of the timbers should increase with their lengths, so that those cut for a high or wide road must be thicker than those used in roadways of smaller dimensions.

In timbering Longwall workings, or the pillar workings of Post and Stall, besides the props cut the height of the seam with lids placed over them of about 15 inches long, "cogs" or "chocks" are used. No drawing is here given of these, as many examples are shown in the next chapter. They are pieces of timber about 2 feet long and from 6 to 12 inches square. If it is intended to recover them, a little rubbish is laid on the floor, and two of these timbers are laid on this parallel to each other and about 18 inches apart. Two similar pieces are then placed on these crosswise, also 18 inches apart, parallel to each other, and at right angles to the two first laid. Two more similar pieces are placed over the last in a line with the first two laid, and so on till the roof is reached, where they are wedged with pieces of chip.

Chocks which are to be taken out and used over and over again are generally made of hard wood, such as oak, elm, or ash, but in cases where no attempt is made to recover them ordinary soft round pit timber is used with the bark on, the latter being often 4 or 6-foot timbers. If intended to be left in, the space between them is filled with rubbish as they are built up.

Figs. 148 and 149 show a form of timbering employed in France, as described by André in his *Treatise on Coal Mining*, the chief features of which are the struts supporting the props and the collar at the point where they have a tendency to give way, and also the use of longitudinal pieces to bind the different sets together.

Fig. 148 shows the arrangement for a road having a single, and Fig. 149 that for a road having a double line of rails. The operation of fixing the bracing pieces inside the other usual set of timber is as follows:—

The longitudinal immediately under the collar is placed and temporarily held

there by pieces of wire. The length of the piece is 9 or 10 feet. Next the two side longitudinals are placed and temporarily held in position similarly to the one immediately under the collar. Two or three upright struts are then placed under the side longitudinals, and afterwards some of the upper struts are inserted

Scale. 6 Feet to 1 Inch.

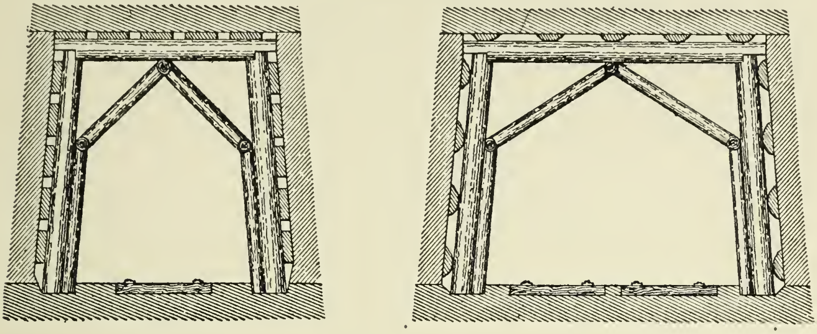


Fig. 148. Fig. 149.

METHODS OF TIMBERING ROADWAYS.

obliquely and driven towards their permanent position. The wires are now removed, and the remaining upright and oblique struts inserted and driven firmly into position by blows from a wooden mallet.

If every set of timber is thus braced it is capable of resisting enormous pressure. The struts and longitudinals are 3 inches in diameter for a single line roadway,

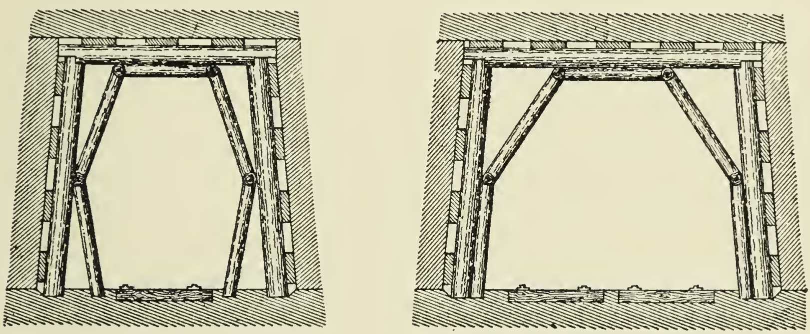


Fig. 150. Fig 151.

METHODS OF TIMBERING ROADWAYS.

and 4 inches for a double line roadway. Figs. 150 and 151 show a modification of the same system of bracing the main timbers.

In Fig. 150 the upright struts, instead of being in contact with the props throughout their length, are set out at the foot, and the oblique struts, instead of supporting one longitudinal in the centre of the collar, support two, which again support a short horizontal strut under the central portion of the collar.

Fig. 151 is much the same as Fig. 150, but is meant for a double line roadway; and in this case the upright struts are in contact with the props throughout their length.

Where the props in any "sets" of timber have lateral pressure thrown on them

it is usual to bind the "set" together by notching the timbers. The notches in the floor prevent the props from being displaced at the bottom, and the notch formed in the collar and props is designed to prevent the lateral pressure from disturbing the position of the props at the head.

There is no doubt that notching weakens the timber, as a portion of the wood is cut away. The notches formed on the collars cut away from $\frac{1}{3}$ to $\frac{1}{2}$ of their thickness at that point. But no great objection arises from this weakening, because the collar, after being notched, placed in position, and supported immediately under the notch by a prop, is still much stronger at that point than in the centre. If any roadway be carefully examined it will found that the collars nearly always break in the centre or at a distance from the notch.

Figs. 141 and 142 show a method of slightly notching, in which the prop is left

Scale. 6 Feet to 1 Inch.

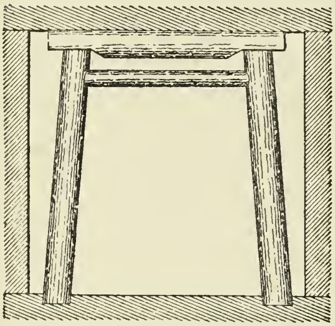


Fig. 152.

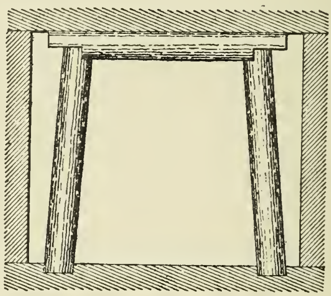


Fig. 153.

Fig. 154.

METHODS OF TIMBERING ROADWAYS.

cut off square, and the collar is cut away on either side with an axe sufficiently to give a flat bearing surface.

Figs. 143 and 144 show another method, in which the upper end of the prop is hollowed out with an axe to receive the rounded ends of the collar, which is not cut. There is much less protection from lateral pressure in timbers cut thus, but it may sometimes be a convenient arrangement for fixing sets of timber where there is little or no side pressure.

Fig. 152 shows the same arrangement of notching as Figs. 141 and 142, with a stay placed across between the two props, the stay being hollowed out to receive the props.

If the lateral pressure is greater than the pressure from the roof, the props will be knocked out by it unless a better form of notch be adopted, such as shown in Figs. 153 and 154, which is cut in both collar and the props. The lateral pressure sometimes causes the collar to split; to prevent this a stay may be inserted similar to that in Fig. 152.

In Figs. 155 and 156 the Welsh system of notching timber is shown. This notch is formed in placing the sets of timber at the most important collieries in South Wales, in many of which the side pressure to be resisted is enormous. No stay is required with this notch, and the collar may be sawn to the length shown on the figures, or it may be rather longer. The shape of the roadway determines this. The prop ordinarily is in contact with the collar for 3 inches on the inside, or nearest the centre of the road, and for 4 inches on the outside.

Frequently a loose stone at the side of a roadway requires support. It may be thick and partly protected by the roof, or partly by the side, but having a

weak place it must be secured, if it cannot be taken down. In circumstances which admit of it, a prop and lid are placed under it; in others, the prop has to be placed in an oblique position, either being set on the floor or the other side of the roadway. In such cases a good plan is to slightly scoop out in a curved form the top of the post, and then to have a wedge-shaped piece having a rounded bottom to fit the prop, and a flat top surface. It may then be driven in over the prop by blows from a hammer till tension is obtained.

Cast-iron props have occasionally been used, but their inelasticity or brittleness is a great objection, and this, probably, more than the cost, has prevented their coming into general favour. Where the pressure is great a metal prop breaks suddenly without warning, and has none of the bending property of timber, which, as a rule, shows signs of giving way, thus allowing time for repairs or renewal.

Wrought-iron and steel are also used to some extent for securing underground roadways. In main roads which are likely to be used for years, and which, if timbered, would necessitate the renewal of the timber every two or three

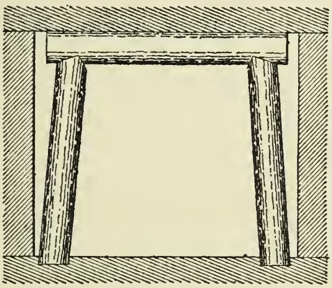


Fig. 155.

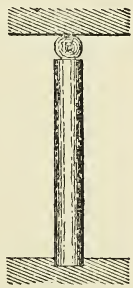


Fig. 156.

Timbering a Roadway.

years, it would probably be cheaper in the long run to adopt iron or steel. Although the first cost of these materials is relatively high as compared with timber, there is no comparison in their serviceableness; beside which the iron or steel, if recovered, even if bent or broken, is still worth a considerable part of the first cost. There is, however, this great convenience in the use of timber, which is wanting in iron or steel, that it may be cut to suit any size of roadway.

Timber is usually bought in large quantities. To prevent its deterioration care should be taken in the storing, which is best done in a covered building placed, for convenience, near the shafts. The pieces should be placed horizontally, and crosswise, to allow air to circulate, and means should be taken to ventilate the building. The small timber should be placed on end. When using from the store-room, the oldest stock should be used first.

Some roofs fall for a few feet upwards to a harder rock, and advantage is taken of this fact by allowing the fall to go on for a time, and then, after it has ceased, the permanent road is made with little or no timber under the harder rock. Other roofs will fall to an indefinite height, necessitating walling in the main roads. It is much better to let the goaf* settle before putting in

* *Goaf* or *gob* is the name given to the space from which coal or other mineral has been entirely worked. There is usually more or less of this space *open* at and near the edges of an area from which the mineral has been entirely extracted, the closing of the interior depending upon (1) the nature of the roof and floor, and their capability of resisting the incumbent pressure, and (2) the amount of packing built and the débris thrown back into the goaf in the process of working. In general, the interiors of large goaves are practically closed.

walling, if even the road has to be timbered for a year or two before the walling is built. Sometimes, in working thick seams, a bad roof over the coal prevents roads being carried immediately under it. In this case the top bed of coal is often allowed to remain, thus affording a better roof than that over the coal.

Wherever timber is placed in damp situations it is affected injuriously by the watery vapour in the atmosphere. Some kinds of timber decay more rapidly than others where so exposed. English larch stands a considerable time in damp places, but any timber used in wet roadways may be rendered twice as durable by "creosoting." 100 parts of coal tar contain, when distilled, 65 parts of pitch, 20 of essential oil (creosote), 10 of naphtha, and 5 of ammonia. The oil produced from this distillation is used for creosoting timber. It prevents the absorption of moisture in any form, under any temperature. It is noxious to animal and vegetable life, repelling the attacks of insects, and preventing the propagation of fungi. The oil is injected at a temperature of 120° F. under a pressure of 150 lbs. per square inch, so that ordinary fir timber absorbs about 8 or 10 lbs. weight of creosote per cubic foot.

In return airways which are damp and warm ordinary timber soon rots, and if its use cannot be dispensed with in these situations, it should be creosoted before being placed there.

In many districts props and sprags are used at the working faces to prevent the coal from falling on the workmen whilst engaged at their work. As the system of propping the coal is inseparably connected with the mode of working, which again is regulated by considerations respecting the seam, we reserve our remarks on these subjects until the next chapter, when the systems of propping and spragging the coal will be dealt with, and many examples shown of what is being actually done.

In Northumberland and Durham skilled workmen called deputies are employed. The duties of a deputy for the most part consist in setting and drawing timber in any district over which he has charge. Besides the timbering, he lays the rails where required, and takes up any from recently abandoned roads, and also attends to the bratticing, ventilating doors, &c. Usually he has about a dozen men to attend upon in his district.

In the counties mentioned the workmen at the face are relieved of the responsibility of propping the roof, which responsibility devolves on the deputies, who are officials acting on behalf of the owners, and in these districts, where the roofs are fairly good, this plan seems to work well.

In Derbyshire and Staffordshire a kind of Butty system is in vogue, in which stallmen have charge of the Longwall faces, receiving a tonnage or contract price on the coal sent out, and these stallmen employ workmen to hole and take down the coal, whilst they or others employed by them put in the props and build the pack-walls. A stallman has from 8 to 16 men under him.

The usual arrangement is for the miners or persons working at the face to set all the timber required there for their own protection and a great deal may be said in favour of the arrangement, but it should always be under supervision from the officials, and subject to some kind of regulation as to the extreme distance allowed between props, &c., according to the requirements of the case.

The timbering on the main roads is done by timbermen appointed for the purpose.

WALLING.—The roadways forming the main underground arteries are frequently walled. Sometimes the walling is continuous over long distances, at others where the road has passed here and there through weak beds the walling is in short

pieces. Air-crossings may require walling, and the spaces between doorposts and the road sides where important doors are fixed. Walling may be of stone or brickwork. If stone is used the hard sandstones of the coal measures are found very suitable and are much harder than ordinary bricks. Bricks, however, are very convenient to handle, and may be moulded to suit the curve of any archway, whereas the hard sandstones require a considerable amount of dressing if used for arching. Sometimes, where arches have to be turned the side walls are of stone and the arch bricked.

Scale. 4 Feet to 1 Inch.

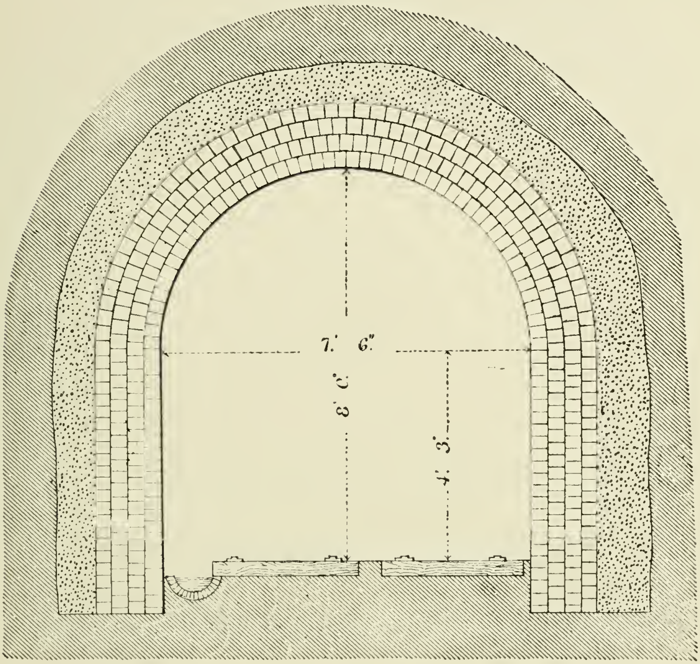


Fig. 157.—Method of Securing a Roadway having a Good Floor but a Bad Roof and Sides, by means of Side Walls and Semi-circular Arch.

Where the roof is good and only the sides bad, walls of stone or bricks may be built from a few inches below the floor line to the roof on each side. The thickness of masonry will depend upon the nature of the rock, but should not be less than 9 inches. Very little mortar should be used between the stones or the bricks in building. If the floor and sides are strong and the roof bad, an arch may be turned resting on the side rock. If one side and the roof are bad a wall is built next the bad side and the arch turned resting on this side wall and the firm rock on the other side. When both sides and the roof are bad two side walls may be built and an arch turned resting on them. An arch which is semi-circular in shape, is shown in Fig. 157. The size on the drawing is for a double line of rails, and a gutter for carrying the water is shown at the side. Where the floor is bad as well as the sides and roof, the side walls may be built on an invert as

shown in Fig. 158. Where a considerable amount of lateral pressure is expected, and the upright side walls are not calculated to resist it, the roadway may be walled as shown in Fig. 159. This form of arching is usually adopted for railway tunnels, the sides and roof, forming part of an ellipse, resting on an invert and sometimes called a "horse-shoe" arch. Fig. 160 shows an elliptically arched roadway,

Scale. 4 Feet to 1 Inch.

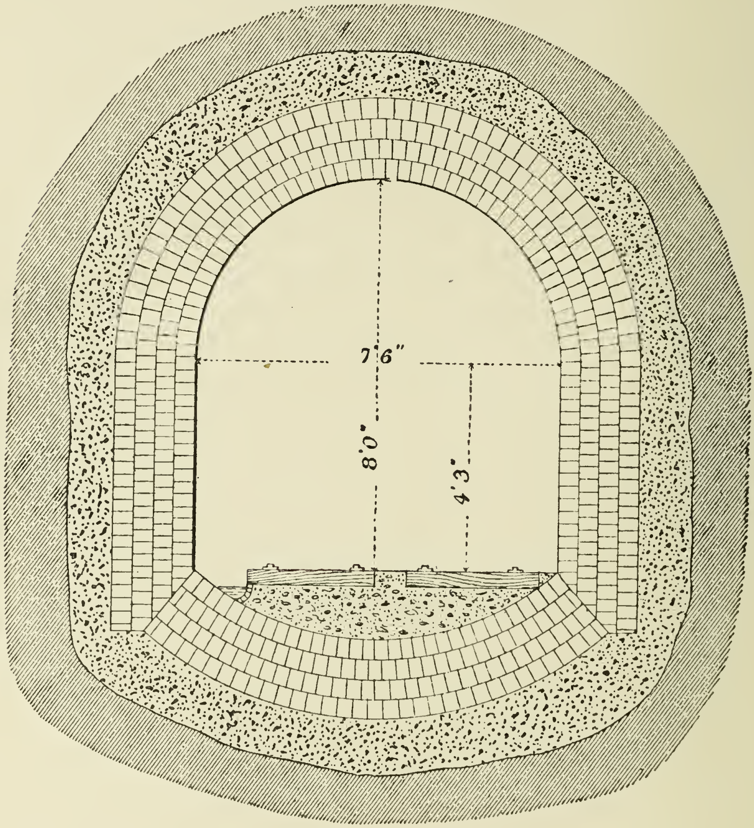


Fig. 158.—Method of securing a Roadway by Walling with Upright Sides, over which is turned a Semi-circular Arch and underneath an "Invert." or Flat Segment Arch.

which is the strongest form that is suitable for underground roadways (the circular not being practicable), and will resist pressure from any direction better than any of the other forms given. The masonry is built in such lengths as the strength of the rock will permit, and if found necessary, temporary timber must be set.

Where timber is used, the length of masonry put in must be a short one, as the timber has to be taken out gradually. Very little should be removed at a time, and when removed the walling should be built rapidly so as to support the roof where previously timbered, without loss of time.

In the case of an arch having an invert, the invert is first built, the necessary rock having been taken out below the floor line and at the road sides. The invert

is kept in advance of the side walls and the arching, and centering is used in building it.

The side walls are built on the invert and are kept in advance of the arching, so that the masonry may be said to proceed in three sections. A staging is erected from which the masons build the arch over the side walls. If no invert is

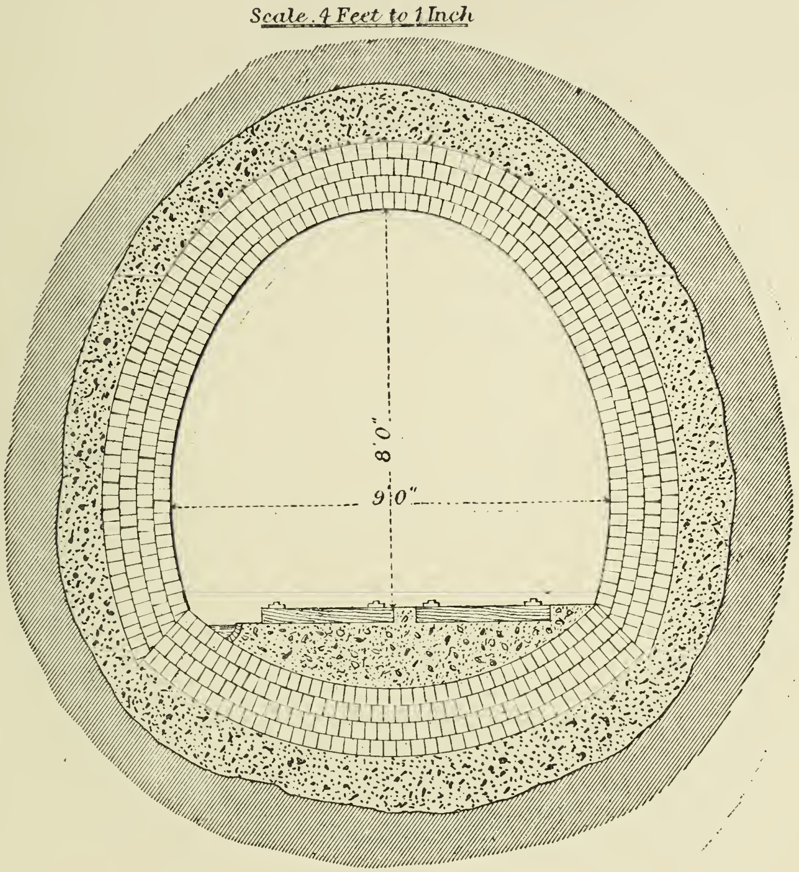


Fig. 159.—Arching for Underground Roadway where the Sides and Roof form part of an Ellipse, and the Floor an "Invert" or Flat Segment Arch.

required, the masonry proceeds in two sections, the side walls being kept in advance of the arching.

Iron centres instead of the usual wooden ones are used for turning the invert and arch. Blocks are fixed on the floor to take those for the invert. The centres for the arching may rest on blocks slightly projecting from the side walls after they are built.

All old timber should be taken out if possible, and the space behind the walls and over the arch should be tightly packed with rough concrete, or any suitable material. Timber left behind the masonry would rot in time and leave spaces between the masonry and the rock. If the masonry is proceeding in a road to which accumulations of fire-damp may possibly extend, care must be taken to prevent

open lights being taken above the arch, even if these are permitted in the roadway.

Roads requiring to be walled, as shown in Fig. 157, may have the necessary

Scale. 4 Feet to 1 Inch.

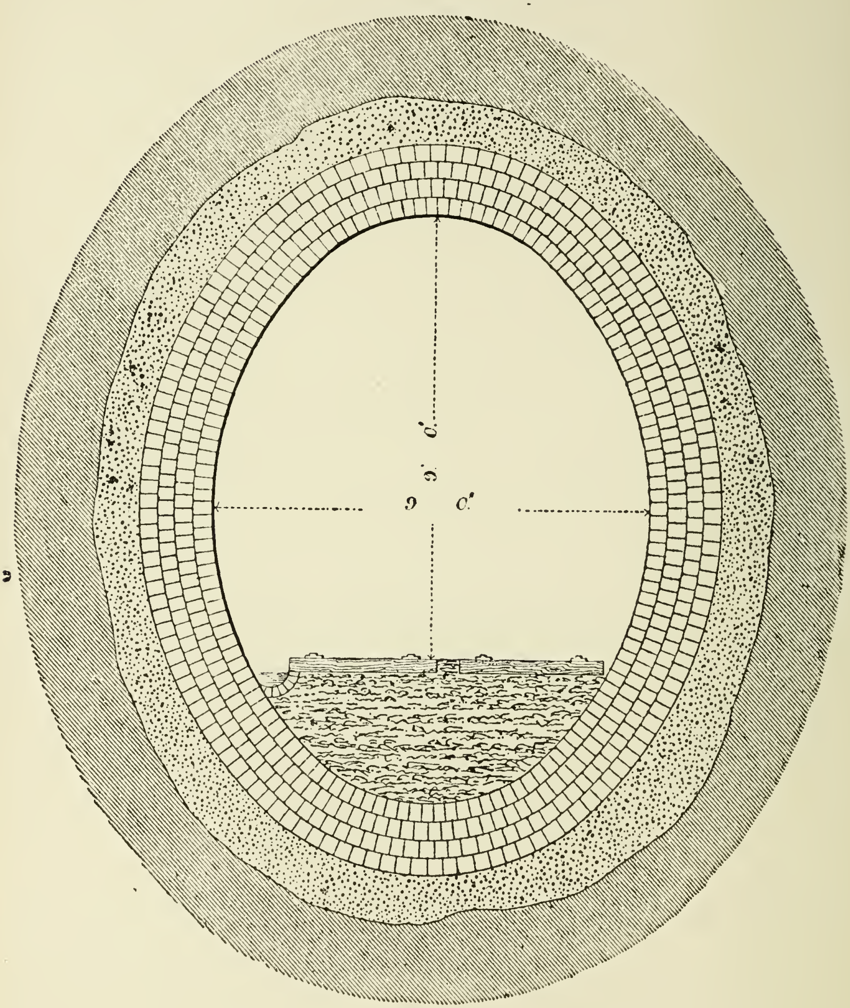


Fig. 160.—Section of Elliptically Arched Roadway, having One Foot of Sand interposed between the Arching and Stratification, and showing a Double Line of Rails laid, and Gutter formed in it.

material taken from the sides and roof, to admit of the masonry being put in during the day-time, without interfering with the usual traffic (if that be limited); so also, by using the iron centerings which do not obstruct the roadway so much as he ordinary wooden ones do, the masons may put in the walling whilst the usual work of the colliery proceeds. But if the quantity of coal passing along the road

is large, it will be better to arrange that the work be done at nights. Where an invert to the arch is required, the work must be carried on during the night unless the road is free from traffic.

It is better in all these operations to use hydraulic mortar, because it sets so quickly: some hydraulic mortars become solid in quarter of an hour either in the air or under water.

Where the depth from the surface and consequently the crush, is great, arches however strongly built are often destroyed by its force. It has been found that by packing the top and sides with sand, to a thickness of not less than one foot, the weight is distributed over the whole surface of the arch, and the walling has remained intact. The thickness of masonry required to resist a given pressure is less if packed firmly behind with sand than would be necessary if no packing be used. In the drawings Figs. 157 to 160, the different forms of arch are shown with the packing of sand filled in behind.

CHAPTER VII.

NARROW WORK AND METHODS OF WORKING.

Shaft Pillars—Water-Levels—Cross-measure Drifts from Shafts sunk through inclined strata—Stone Drifts through faults—Longwall Method of Working—Post and Stall System—Different Arrangements of Single Road Stall Working—Double Road Stall Method and its Modifications—Method of Working and Timbering adopted at the following Collieries:—Celynen, Risca, and the Ocean—Wicket System of North Wales—The Bank System of South Yorkshire—Method of Working and Timbering adopted at the following Collieries: —Lundhill, Kiveton Park, High Park, Wearmouth, Silksworth, Florence, Great Fenton, Cannock and Rugely, Pemberton, Clifton Hall, Pendlebury, Sovereign, Radstock, Kingswood, Allanshaw, Cowdenbeath—Working thin seams in Northern France and Belgium—Square-work Working of the Staffordshire thick coal seam—Working the thick coal seams of Poland, Upper Silesia, and Bohemia—Dealing with excessively thick coal seams by Longwall and Post and Stall—Questions and Answers bearing on the subjects of the Chapter.

After the shafts have been sunk, drivings will be necessary to win the coal, and one of the first things to consider is the size of pillar or pillars to be left for the support of the shaft. If no pillar were left, but a longwall face opened at once from the shaft on either side of it, the subsidence of the roof, except in very thin seams, consequent on such proceeding would disturb the strata near the pit, and might cause injury to the shaft-walling, displace the shaft-fittings, and entail a considerable after-expense in restoring the shaft to a working condition. The size of the shaft pillar or pillars should be such that, when the coal is worked away beyond a sufficient area round, the shaft will be unaffected by the "draw"—the lateral disturbance of the strata beyond the point actually worked. The depth from the surface, the nature of the strata above and below the coal seam, as well as that of the coal itself, and the amount of dip all influence this. For any depth to 100 yards, it may be sufficient to leave a pillar 40 yards square. Adopting this size as a minimum we may fix any size of pillar for greater depths by increasing the pillar 5 yards for every 20 yards in depth, so that for a shaft 150 yards deep, we should require a pillar $52\frac{1}{2}$ yards square, for a shaft 200 yards deep, 65 yards square, for a shaft 300 yards deep, 90 yards square, for a shaft 400 yards deep, 115 yards square, and so on.

The shaft should always be in the centre of the pillar or pillars left for its support, to ensure the same amount of protection on each side.

If water is likely to be met with, water-levels will be required, and these should be started some feet below the seam at the pit bottom. Roadways in the seam to be "water-level" should rise slightly, about $\frac{3}{16}$ths of an inch per yard, to allow the water to flow out to the shaft. For the purpose of ventilation, the two shafts, which are necessary to every colliery, are also connected as soon as possible by driving in the seam. Levels are usually driven on both sides of the shaft, and there may be either two or three on each side, driven parallel to one another, and about 20 or 25 yards apart. They are generally driven from 7 to 10 feet wide; if the roof be very bad, it may be desirable to make them as narrow as 5 feet. With regard to height, if the seam is thicker than 7 or 8 feet, the level is usually carried that height, and the upper portion of coal left as the roof. If the seam is less than 5 feet high, the roof is ripped down or the bottom cut to

make height on the upper level, and when finished the road should be 6 or 7 feet high. The levels may be timbered or walled if the top is bad. For the purpose of ventilation they are connected every 30 or 40 yards by cross-holings driven at right angles. As soon as a fresh one is cut through, the previous one is closed by a brick or stone stopping built in it so as to keep the air well up to the face.

If the seams of coal to be won lie at a high angle of inclination, it is usual to sink the shafts below the seams and drive a cross-measure or stone drift, water level, from the shaft across the barren ground until it intercepts the seam or seams

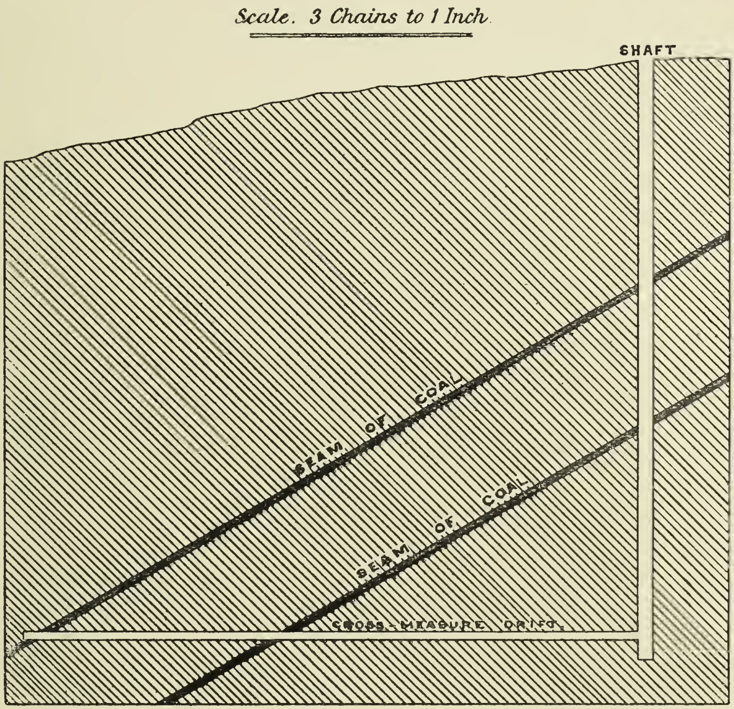


Fig. 161.—Section showing Cross-measure. Drift driven from the Shaft to two Coal-seams lying at an angle of 30°.

of coal. Fig. 161 is an example of this, where a cross-measure drift is shown extending from the shaft to two seams of coal which lie at an angle of 30 degrees. At the point where the drift intersects the seam of coal, water levels are turned opposite each other from either side of the drift. For the purpose of ventilation, if a pair of drifts are not proceeding, air boxes or brattice are used as a temporary expedient, until a return air-way is driven in the seam of coal, back to the upcast shaft.

At times it is desirable to make stone drifts from one seam to another, or through a fault to intercept the same seam of coal on its other side. Fig. 162 is intended to show an example of this kind. The workings after proceeding to the rise on No. 1 and No. 2 seams have stopped at a downthrow fault. If stone drifts be now carried at water level as shown in the two positions on the section from No. 2 seam, the upper cross-measure drift will

cut the No. 1 seam on the other side of the fault, while the lower and longer one will prove the No. 2 seam on the far side of the fault, and these seams being connected by an air pit, working may be resumed on them inside the fault.

Instead of driving the two drifts as shown, the upper one might be continued water level past the point of cutting the No. 1, till it reaches the No. 2 seam,

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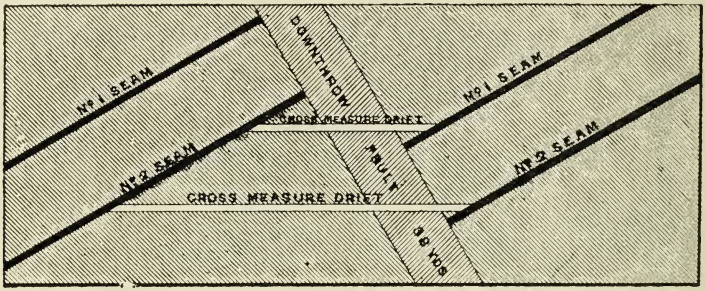

Fig. 162.—Driving through a Fault.

after which, to form a return air-way, the air-shaft between the seams must be sunk inside the fault, and another stone drift must be driven parallel to the first, and extending from No. 1 to No. 2 seams on opposite sides of the fault.

In Fig. 163, the workings of two seams lying level are shown as having proceeded against an upthrow fault, and here the cross-measure drift is made to rise

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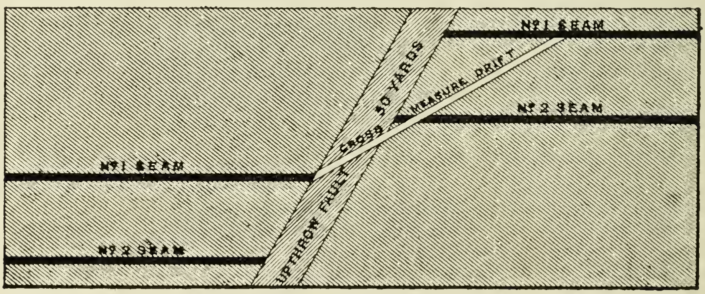

Fig. 163.—Driving through a Fault.

rapidly in order to cut the seams thrown up. After the cross-measure drift has proved the two seams as shown on the section, it will be necessary that another be driven parallel to the first, either all the way, or parallel to the first through the part of its course from No. 1 to No. 2 seams on opposite sides of the fault, when the working of No. 2 seam where just proved through the fault may be continued, and an air-pit sunk to connect the two seams at the higher side of the fault.

The rock between seams may be removed upwards or downwards from the lower to the upper seam or *vice versâ*, for the purpose of making an air-shaft.

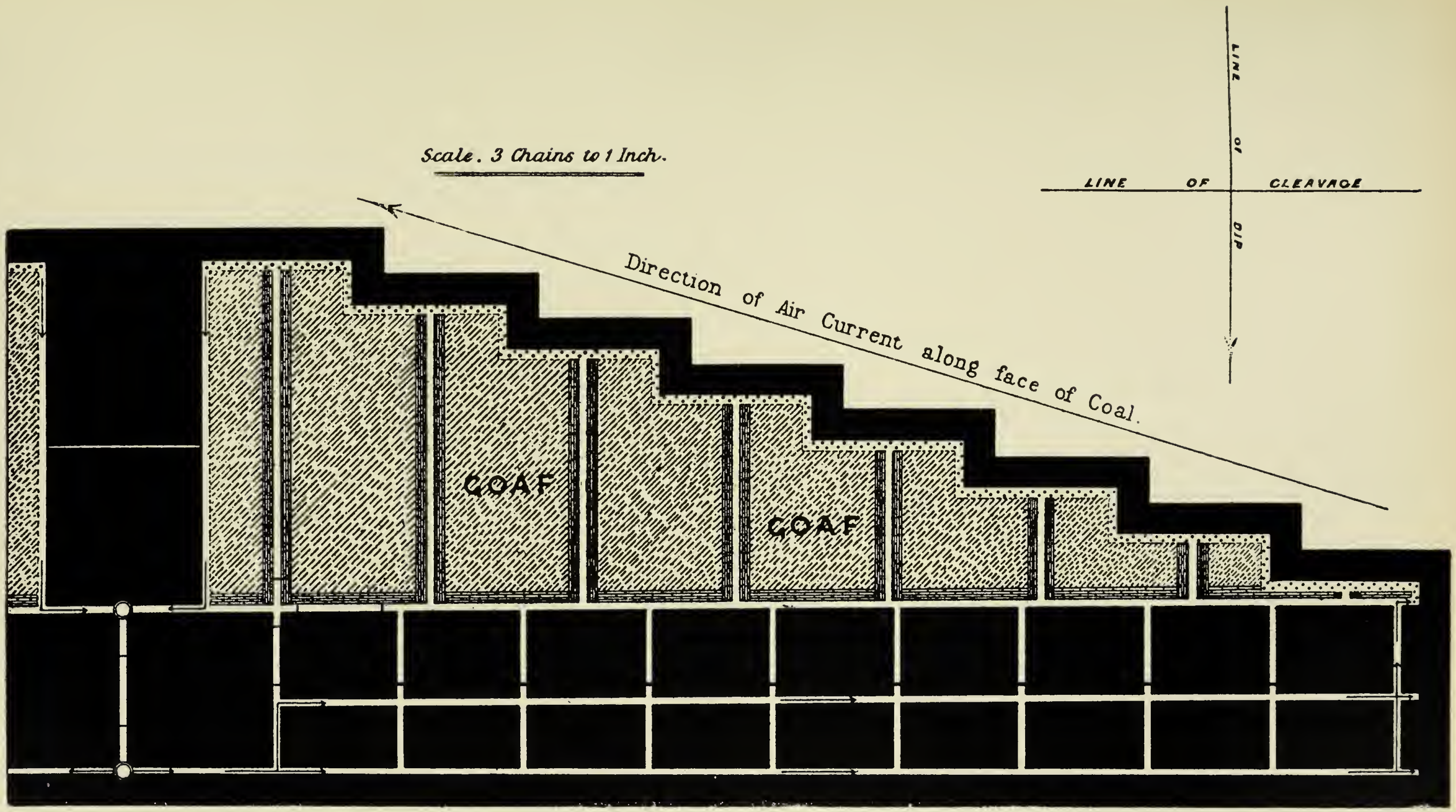

Fig. 164.—Plan showing Longwall Workings with Gob Roads advancing to the Rise and across the Cleavage.

These double communications are necessary for an intake and return air-way, and when made, the working of the No. 1 seam may be resumed inside the fault.

Although only these examples are here given, the student will readily imagine others in which the seams are cut off or interfered with by faults of different magnitudes.

The usual systems of working are what are termed "Longwall" and "Post and Stall," sometimes called "Bord and Pillar," and in Scotland "Stoop and Room." Some systems of working are practised which are modifications of these and seams of exceptional thickness are often worked by a special method applicable only to the particular circumstances prevailing. The circumstances most favourable to Longwall are, a seam, not too thick, of rather hard coal, capable of bearing pressure, and which parts freely from the roof; a seam of coal having stone bands in it or ironstone over it to be worked with the coal, yielding material for packing. The circumstances most favourable to Post and Stall are, seams situated near the surface, the working of which on the Longwall would probably injure the buildings, but which may be worked on the Post and Stall in the whole mine, leaving the pillars, more or less robbed, to support the surface; this system is preferable also where the coal is tender under a heavy roof.

The advantages of working the Longwall where it is applicable are, a better yield of large coal, less injury to upper seams as the intermediate strata settle gradually, simplicity of working, ease of ventilating, and greater economy, for the superincumbent weight reduces the labour of "holing." These advantages are so manifest as to indicate the desirability of working all seams of usual thickness situated 100 fathoms or more below the surface on the Longwall system. There are many modifications of Longwall, and this is one of its merits; it is capable of being varied more readily than the Post and Stall to suit local circumstances. In all cases it consists of extracting all the coal at one operation, the roof settling down behind as the "face" advances. In practice it is generally found better to take out all the coal with the exception of the shaft pillars, but sometimes pillars are left between, and on each side of, the main roads. There is an advantage in letting the face advance across the cleavage of the coal, but some coals have no defined cleavage, and sometimes, even where there is a cleavage, the dip is not suitable for the face to advance across it. In Fig. 164 the gob roads are carried to the rise and across the cleavage of the coal. The distance of these gob roads apart varies, being seldom under 14 yards or over 50 yards. The roads are carried in the middle of the stall, for convenience in working the coal and in bringing it from both sides as shown on the plan, Fig. 164. The pack-walls are built as shown, and if the seam be thin, height is made by ripping either top or bottom. The gob must be packed with the rubbish yielded by the seam in being worked and by the rippings, and the closer it is packed the better will be the result. This is especially necessary in fiery seams, for it must be remembered that any portions of the waste not closely gobbed afterwards become receptacles for fire-damp, unless ventilated. At times, when the barometer is low, a portion of this gas finds its way into the roads, and is at all times a source of dread and anxiety. If the roof is bad a double row, and sometimes a treble row of props, with lids placed over them, is kept next the face, the back ones being taken out, where this can be done with comparative safety, and re-set in front as the face advances. In some cases a double row of chocks is used instead of props. Often the water levels from the shaft, instead of running in a line with the cleavage as shown in Fig. 164, will cross it at some angle; if this be a right angle and it is desirable to carry the "face" across the cleavage, Fig. 165 shows the method usually adopted.

The face thus advances against the cleavage, and if the dip and rise be rather great there is an advantage in keeping the gob road at or near one end of the

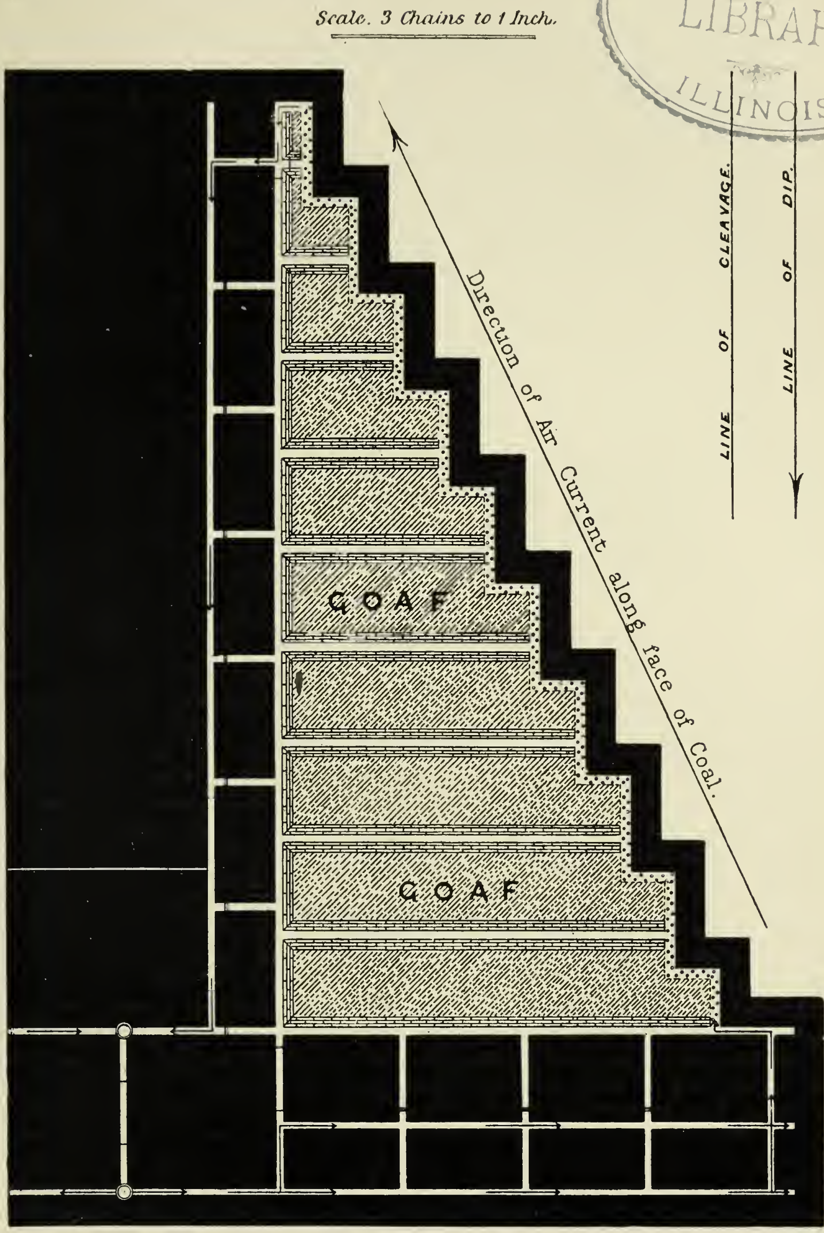

Fig. 165.—Plan showing Longwall Workings with Gob Roads advancing Level Course and across the Cleavage.

working face instead of in the middle, so that the coal may be brought "down hill" to the road. In very tender seams, there is an advantage in working the face *with* the cleavage, instead of *against* it, and frequently, where there is no cleavage in the coal, the face, instead of being marked out in steps, is connected

from one gob road to another in curved lines. If ventilation alone be considered, it is of the utmost importance to have the whole face in a straight or gradually curved line, as this arrangement offers less obstruction to the passage of the air in its course along the face. Whilst fully admitting the importance of ventilation, other points have to be considered and kept in view, and it is not always practicable to keep a face of this shape advancing.

Where there is plenty of capital at command, and the area to be worked over is not great, the levels may, with economy, be driven to the boundary of the royalty and the coal worked back towards the shaft, goaf, which is the most dangerous part of fiery mines being thus left behind.

The Post and Stall system of working is largely practised in the Northern collieries. A set of excavations are driven through the coal parallel with one another, and at certain regular intervals, leaving a rib of coal between them. At

Scale. 13½ Feet to 1 Inch.

Fig. 166.—Effect of "Creep" on the Roadways of a Mine.

right angles to these another set of excavations is driven through the coal, also parallel with one another, and at regular intervals. The effect of these excavations is to leave rectangular blocks of coal which support the roof. Subsequently these blocks of coal are removed. The excavations in the coal alluded to are called *bords* and *headways*. The bords are driven as wide as the strength of the roof admits of, usually 4 or 5 yards wide, and these are carried against or at right angles to the cleavages of the coal. The headways are driven 2 to 3 yards wide in the direction of the planes of cleavage. The blocks of coal between these cross drivings are called pillars, and their size varies in different collieries, and according to the depth from the surface, the usual range being from 20 to 50 yards long, by from 10 to 40 yards wide. The chief consideration in determining the size of pillar is the thickness of cover over it. Both *thrust* and *creep* are caused by insufficient pillars being left. When the roof and floor are of hard, unyielding material, and the pillar of coal left in the first working is too small to support the pressure thrown upon it, the pillar cracks and breaks up, large pieces falling away from it, and finally it is crushed into small coal. This lets down the roof and chokes up the workings, and the action of this pressure is called *thrust*. Again, if the material composing the floor, or both floor and roof, is weak and soft, and the pillars left are too small, the downward pressure upon the pillars causes the floor to rise, and the roof, if of a yielding nature, sinks, the roof and floor thus approaching each other. This is known as *creep*, and is shown at Fig. 166. Indeed, in the majority of mines over 150 fathoms in depth, whatever size the pillars are, if the floor is of fireclay, or any material rather soft, there is trouble in keeping roads and airways open. But, precisely the same thing occurs in Longwall working.

The process of removing the pillars is called *working the broken*, and it was formerly the custom not to begin working the broken until the workings in the whole mine had been carried to their destination, but the leaving of pillars unworked for long periods increases the danger of thrust and creep, and it is

now usual to carry on the two operations simultaneously, the work in the broken following closely upon the work in the whole coal.

There are many ways of working away the pillars. Where these are small they may be removed at one operation, the whole of the coal being taken out and the road formed in the middle of the pillar as the "lift" advances. Circumstances must be favourable to admit of this plan. Again, a lift of half the pillar may be taken off throughout its length, the other half being the subject of another lift. If the seam lies flat, the pillar may be divided into four lifts, proceeding from the four corners of the pillar.

In other cases a narrow place is driven across, splitting the pillar in two and then the two portions of coal left at the sides are brought simultaneously back as "lifts."

It will generally be found that a lift of six yards wide is quite sufficient to take at one time, and in working the coal in the whole mine, pillars should be left of a size suitable to resist the effects of thrust and creep, and yet easily arranged for their ultimate removal. The roof must be good that allows of a lift of 6 yards wide being taken 20 or 25 yards in distance. In the North of England the practice is to timber the waste formed in working any lift, the road being carried on the side next the coal. When the lift is finished, the rails are taken out; and, beginning at the inside end, the deputy takes out the timber, or "draws the jud" as it is called.

In other parts, a pack-wall is built on the waste side of the road which is carried next the coal, as in the last-mentioned case, but here the waste is not kept open until the lift is finished. Timber is kept next the face for its security, the pack-wall and the solid coal protect the road, and the other portion of the waste is allowed to fall as the lift proceeds.

Figs. 167 & 168 show lifts of 6 yards wide being taken out where they have 25 yards to proceed before finishing. The line of face is kept at a good angle, following the whole mine workings, so that the pressure at the goaf edge assists the working (by a steady uniform breaking down of the top) without injuring the coal, and the line of goaf is continuously maintained. It is better that these lifts should proceed only from one side of the pillar, as shown on the plans; and the ventilation should be arranged so that no air, after passing through "broken" workings, will reach workmen in other parts, but be conveyed to the returns direct.

The two important points to be kept in view, in any arrangement for working the broken, are: (1) Working away all the coal in a good marketable condition without leaving stumps to interfere with the uniformity of the top breaking down along the goaf edge; and (2) To carry on this working with the greatest margin of safety to the workmen engaged in the operation. Clearly, any arrangement by which the lifts are taken off at such angles that any one of them may have goaf on either side will result in the workman on that lift getting daily into a more dangerous position. In Figs. 167 and 168 it will be observed that the lifts have goaf only on one side, and the solid on the other affords protection to the workmen.

Further reference will be made to pillar working later on, when the practice at some collieries will be given in detail.

It was at one time thought that by laying out the workings into *panels* of moderate area, a certain amount of protection from thrust and creep was afforded.

By what is called *panel* working, one district is separated from another by a rib of coal which may be 40, 50, or 60 yards wide. The advocates of the system further claimed for it protection in times of explosion of inflammable gas, their contention being that the damage resulting would be confined to the district in which the explosion occurred.

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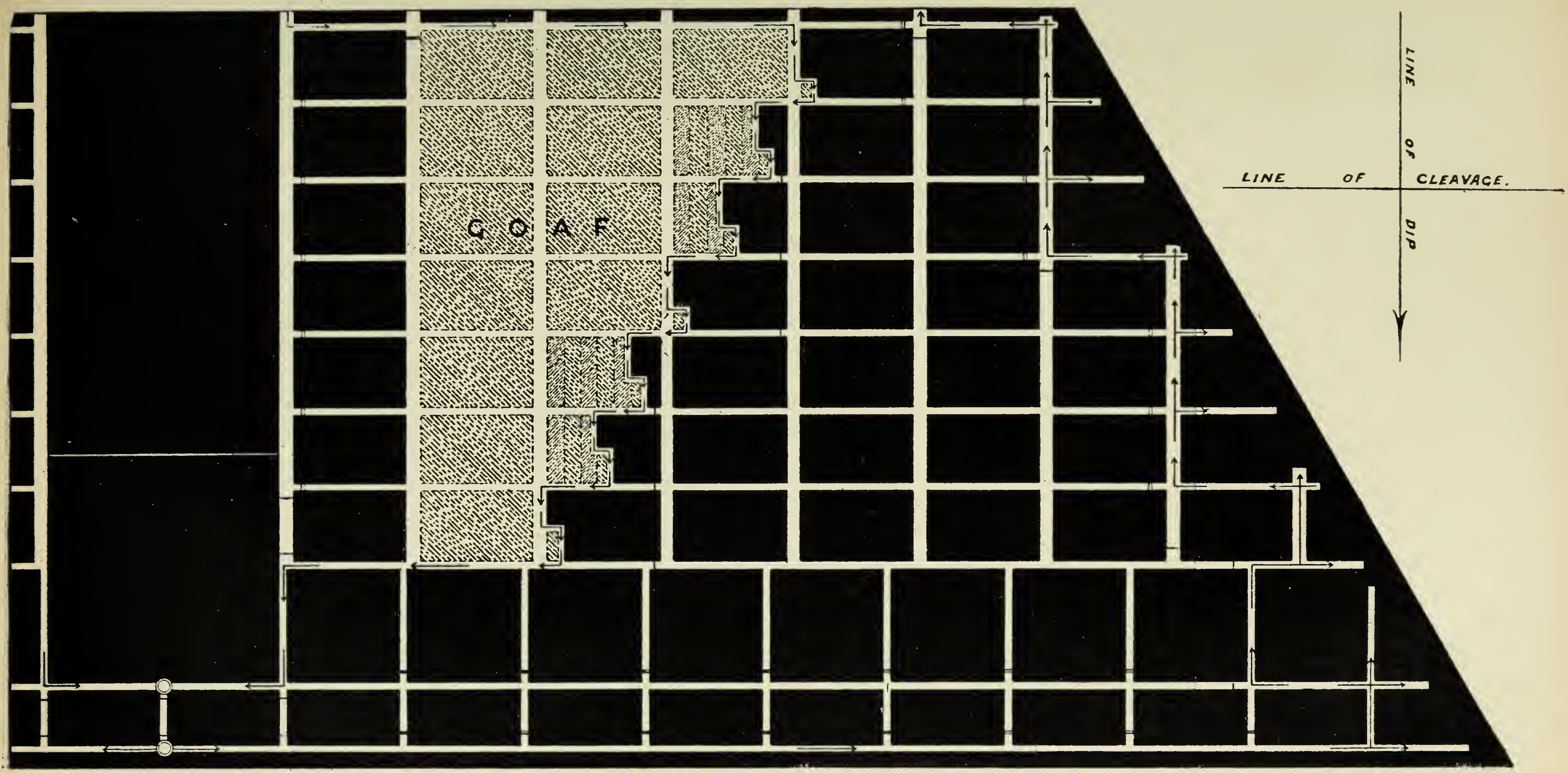


Fig. 167.—Post and Stall system of Working where the Levels are proceeding in the direction of the Cleavage.

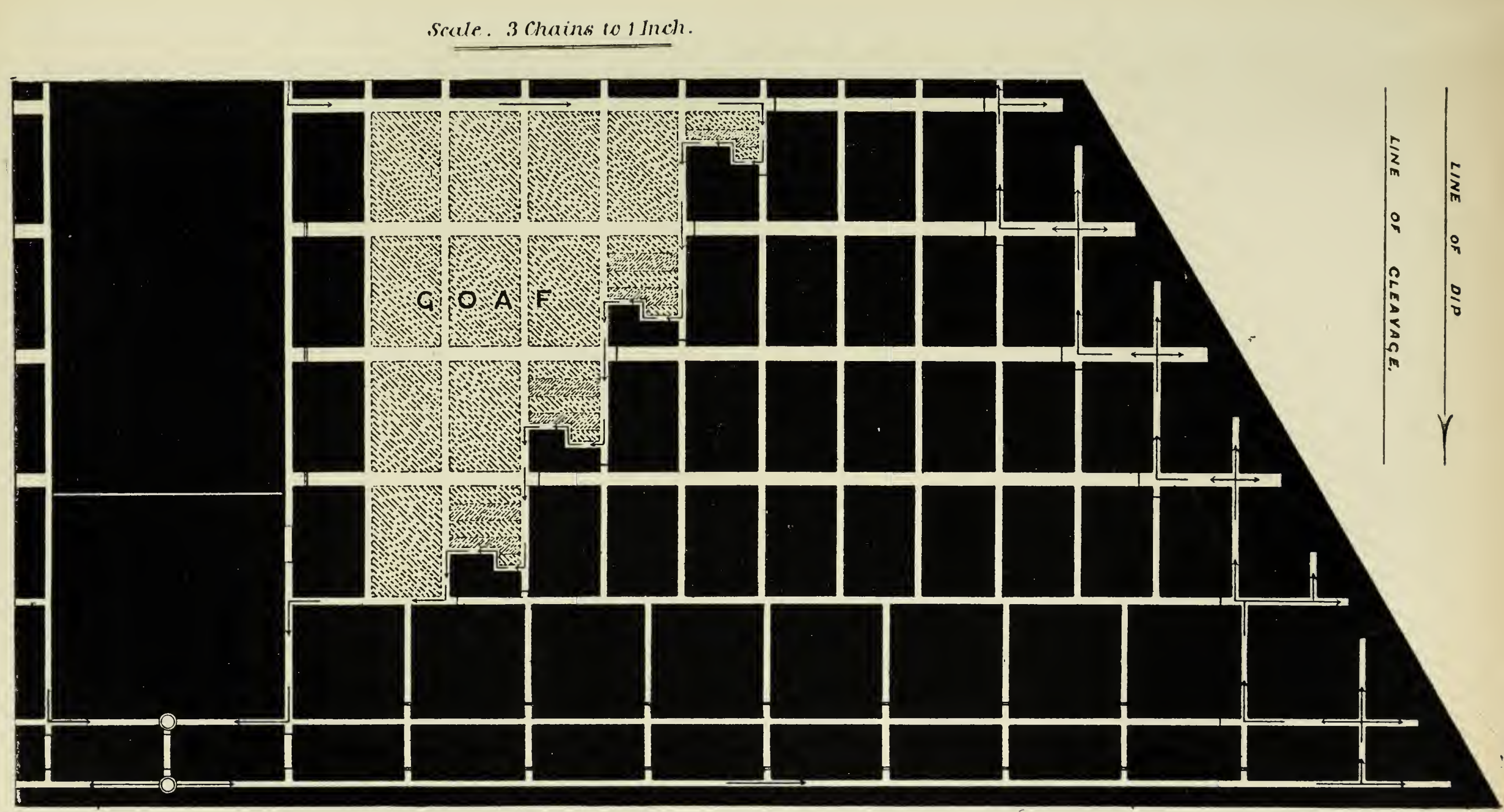


Fig. 168.—Post and Stall System of Working where the Levels are proceeding across the Planes of Cleavage.

A rib 40, 50 or 60 yards will have very little effect in preventing thrust and creep, if the pillars be left too small, and any good resulting in that direction must be very limited. As before stated, the only effectual means of guarding against thrust and creep, is by leaving pillars of a suitable size.

Then again, the rib of coal has very little effect on the damage caused by explosions of firedamp, for in all cases, it is proved by the blown-out stoppings, disarranged timber, and other indications that an explosion of this kind, wherever it occurs in the workings, takes a course against the intake air-current, and as long as there is sufficient gas to mix explosively with the air, so long will the ignited mass continue its course, often ending only at the downcast shaft. A judicious splitting of the air-currents, then, affords more protection from the effects of an explosion than any system of panel working.

Fig. 167 explains the post and stall system of working where the levels have followed the direction of the cleavage and where the working of the broken follows closely upon the working in the whole mine.

If the levels have crossed the planes of cleavage at right-angles, the workings would appear as shown on Fig. 168.

In seams having a high inclination it may be required to set away a pair of winning places, or drivings, in a direction neither headways course nor at right angles to it, but midway between the two, and these are called "cross-cuts." They are usually driven by bearings, to keep them in true alignment, and the "marks" may consist of three or more wooden plugs with iron crooks in them, driven into the roof in the required direction. The marks are generally put up by the aid of a surveying dial, and the driving is kept straight by hanging three plumb bobs from the crooks in the plugs and looking in their direction to a light in the face.

In arranging the ventilation of a colliery, air-crossings, doors, brattice cloth, stoppings, and regulators are required. Generally speaking, the aim should be to have as few of these as possible, and to keep doors off main or important roads. In any plans of workings shown, the arrows indicate the direction of the air-current; a X indicates an air-crossing; a single line across the road a door, either of brattice cloth or wood; a double line across the road a permanent stopping.

Two methods of working peculiar to South Wales are the "Single Road" and the "Double Road Stall" systems.

Both systems are capable of modification to suit circumstances. In the Single Stall system shown in the drawing Fig. 169, the usual conditions prevail. Instead of driving a pair of narrow levels from the shaft, which from the difficulty of doing so are saddled with a heavy yardage or driving price, a more economical level is formed. A face sufficiently wide to hold the rubbish yielded in working the seam and usually about 8 yards, is pushed bodily forward on either side of the shaft. The road is made next the coal on the rise side, and an air-course next the coal on the low side, the space between the road and air-course being closely packed with any rubbish yielded in the driving and the ripping of the roadway. A facing of the larger and stronger stones from the ripping of the top or the bottom, as the case may be, is used to form the road side, and when needed the road is timbered. When these levels have proceeded far enough from the shaft to form the shaft pillars, headings are turned, one on either side of the shaft, which are driven to the full rise of the seam. These headings, like the level, are driven 8 yards wide, and have the road formed on one side and the air-course on the other of the advancing face. The heading road is formed on the side farthest from the shaft, and out of it at intervals of 24 yards stalls are turned, as shown on the drawing, and driven level course or parallel with the main level. These stalls are turned narrow from the

heading, being 6 feet wide, and are continued of this width for a few yards in distance, after which they are gradually opened to their full width of 12 yards, as shown on the plan, Fig. 169, but the width of these single road stalls varies according to the amount of rubbish yielded by the seam, and the size of pillar intended to be left; it also varies according to depth from the surface and the nature of the roof and floor.

By this time the main level has advanced sufficiently (dealing with one side of the shaft, as the operations on the two sides are similar) to allow of a narrow driving being made from it to the point in the low side of the stall where it is first opened to its full width. This forms an air-way by which the air passes from the main level into the stall. As the stall is now driven on, the road is made next the coal on the rise side, and an air-course formed next the coal on the lower side. The road thus forms a straight line to the heading, and the air-course is really a continuation at right-angles of the air-course connecting the stall with the main level. The pillar of coal left next the main level and the heading is about 20 yards long, and remains to protect them until they are finished working.

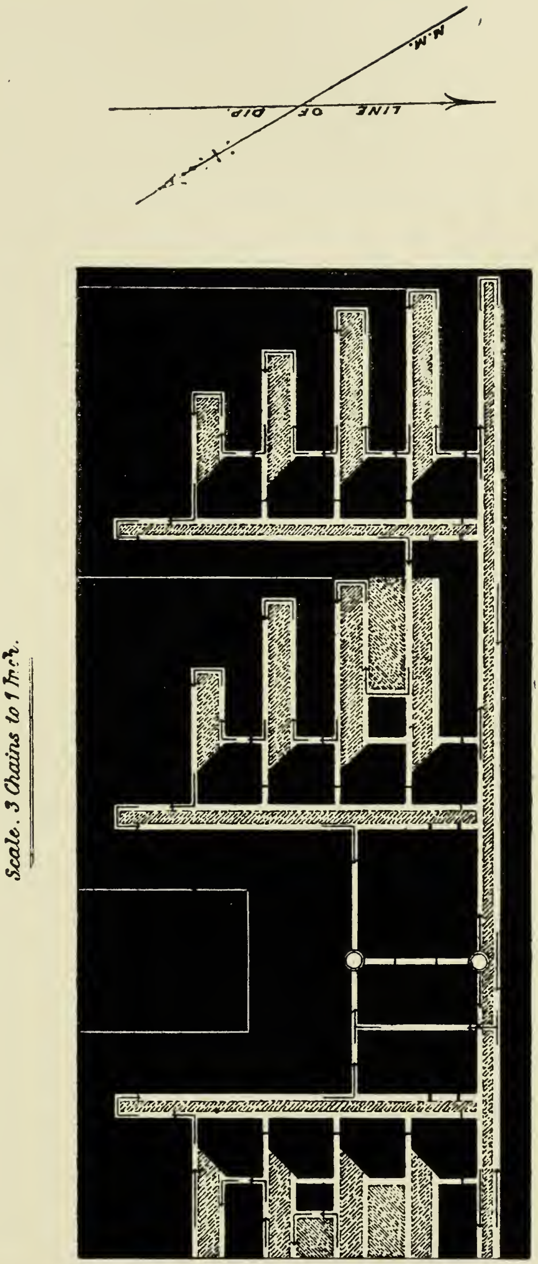


Fig. 169.—Plan showing usual Arrangement of Single Road Stall System of Working Coal in South Wales.

The stall is continued till it has proceeded about 75 yards from the heading, the space between the air-course and road being packed with rubbish. The

coal is brought in boxes along the 12 yards of face to the tram at the end of the road, whence it is conveyed by horses.

When the main level has advanced sufficiently, another heading similar to the first is turned. There are about 90 yards of coal between the two headings. The stall which has reached a point within 15 yards of the second heading is now continued narrow through to this second heading and becomes an air-course, the object being to shorten the distance the air travels and leave a 15-yard pillar for the protection of the second heading on that side.

The first heading having advanced and other stalls having been turned out of it, the pillar belonging to this first-driven stall is now worked back towards the heading. This pillar consists of the 12 yards of coal next the stall road on the rise side and lying between it and the air-course above it. The coal is brought in iron boxes down-hill along the face to the tram, which is brought along the same line of rails as used in driving the stall.

In Fig. 169 this pillar is shown as being partly worked back. When the pillar coal is all taken out to the air-course (which it is necessary to drive between *all* the stalls) it is finished, the stump next the heading being left until the heading is finished, so as to protect it whilst working, but afterwards all the stumps in that particular heading, commencing at the top, or innermost one, may be worked off.

Unless left a sufficient size, the stumps are too much crushed to be worth working. Not much timber is used in well-packed stalls where the roof is strong, but for the most part what is used there and in the pillars is lost. An effort ought to be made to recover at least the timber in the pillar working.

This process is continued, headings being turned at regular distances out of the main level, and these single road stalls turned out of the headings. A rib of coal is left next the main level for its protection during completion, after which it may be worked back from the far end.

Fig. 170 is a drawing of another method of the Single Road Stall system. Here the main level is shown as a narrow driving, but it may be driven precisely as in the last case, shown at Fig. 169. Where the roof is very good, the headings may be driven at greater distances apart from the main level, and instead of having the stalls turned from one side of the headings, they may be turned on both sides, as shown at Fig. 170.

In this case there is a distance of 200 yards between the two headings, and as stalls are to be turned on either side, the best arrangement is to make the heading about 24 yards wide, and to form a road next the coal on either side.

This would allow of two men and a lad, or two men and two lads, working at the face, instead of one man and a lad when only eight yards are taken out. The two roads forming the heading are turned narrow off the main level for a short distance and then opened out towards each other; when connected, the face is carried on. This leaves a stump next the main level. The method of turning and carrying the stalls is the same as that described for Fig. 169, but when they have advanced to a point midway between the headings they meet if the stalls opposite each other are started from the headings at the same time and the rate of progress in each is the same. The pillars are then worked back as in the last case. The chief point of difference consists in the greater distance the stalls are carried, owing to the excellent roof in this instance. Other modifications may suggest themselves as the occasion requires. Sometimes, instead of opening out the stall to its full width on the low side of the road and bringing back the pillar along the rise side, the reverse of this is done. The stall, after being turned narrow, is gradually opened its full width on the rise side of the road, the pillar being brought back along the low side. Again, where the inclination is great, instead of evenly dividing the coal to be taken out between the stall and the

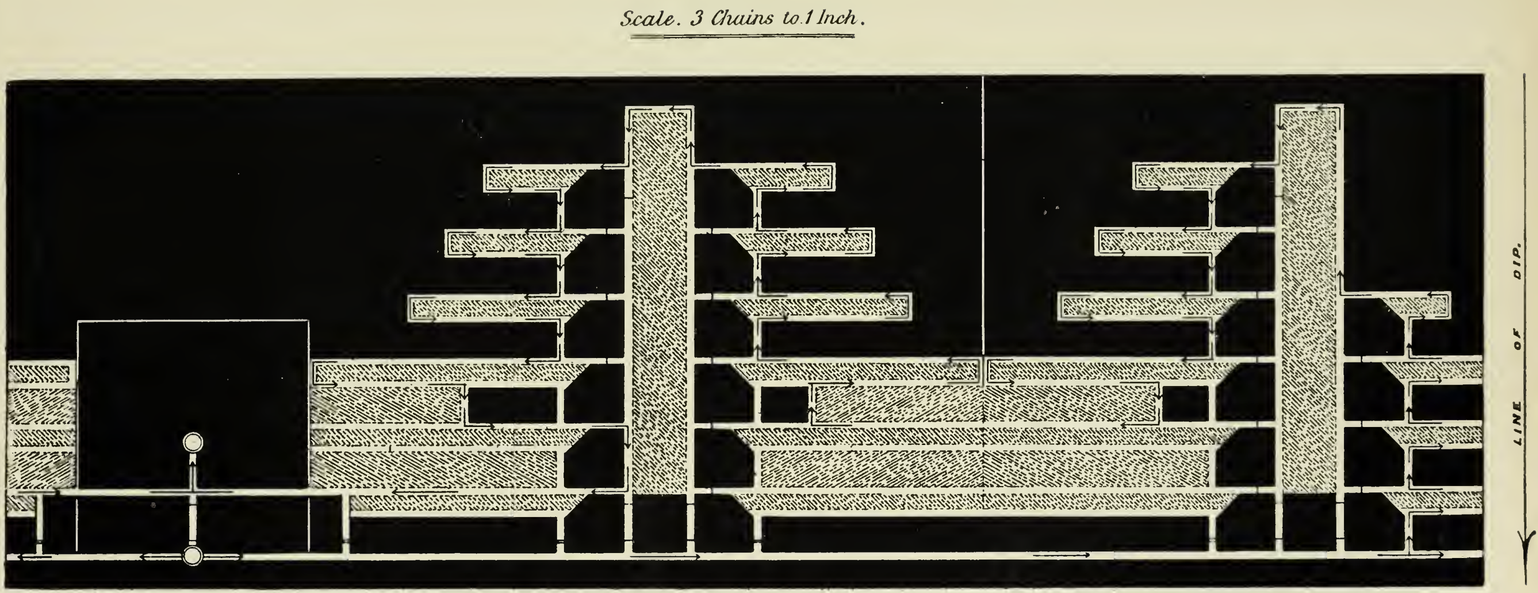


Fig. 170.—Arrangement of the Single Road Stall System of Working Coal in South Wales, where the Roof is very Good.

pillar, some advantage may result from taking, say 14 or 15 yards from the rise side of the road and 8 or 9 yards from the low side.

One man and a boy usually work together in a single stall road, the man

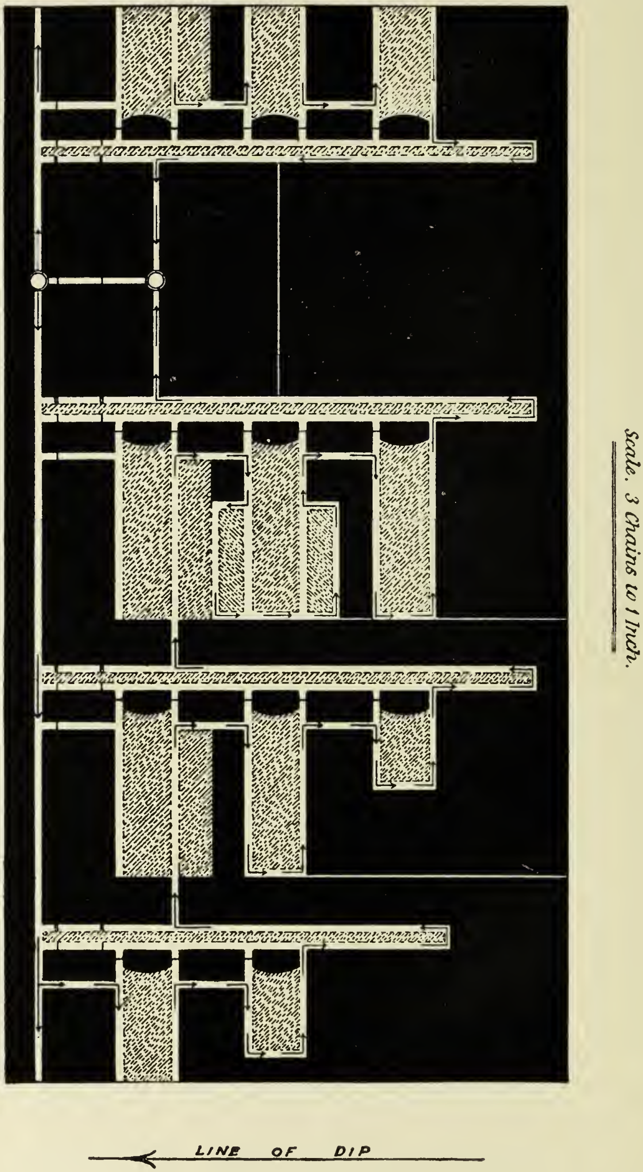


Fig. 171.—Plan showing the Double Stall System of Working Coal in South Wales.

receiving a tonnage price which includes timbering at the face, tramming the coal, and making the road. He pays the boy a daily wage, chiefly to fill the trams for him.

A reference to Fig. 171, and a comparison between it and Figs. 169 and

170, show at once the chief points of difference between the Single Road Stall and the Double Road Stall systems of working. The latter, as shown in Fig. 171, has a main level from the shafts carried as a narrow driving, but it may be carried as shown in Fig. 169. The headings are the same as shown there, and are the same distances apart. Instead, however, of turning a single road out of the headings, two roads, separated by 18 yards of coal at the commencement, are turned and after proceeding a short distance, they are opened out towards each other, and when connected the face advances, being now 22 yards wide. The roads are carried next the solid coal one on each side of the excavated coal, and after proceeding to a point within 15 yards of the next heading, one of the roads (usually the lower one) is continued to the heading as a narrow driving. This afterwards forms the

Scale. 12 Feet to 1 Inch.

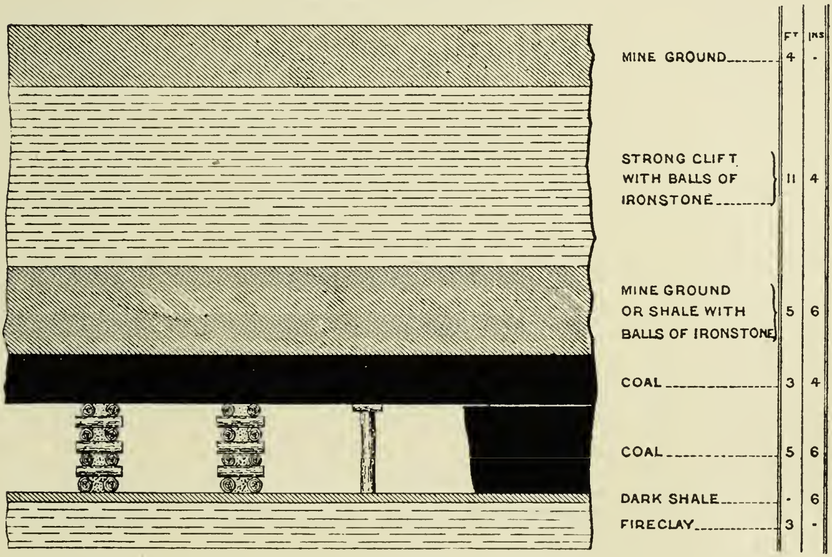


Fig. 172.—Section of the Black Vein at Celynen Colliery, showing also the mode of Securing the Face of a Double Stall Working by Cogs and Props.

air-way, until another is made above it. Two men and two boys work in these stalls, and directly the stall has reached the far end, they divide, a man and a boy taking out half the pillar ($5\frac{1}{2}$ yards) below them, the other man and boy taking half the pillar or a similar distance on the high side. Both parties work their portion of the pillar backwards and finish about the same time. The stumps are left to protect the headings until the last, as are also the ribs of coal next the main level.

The Double Stall is open to modification, as is also the Single Stall, and if the roof is good an arrangement of Double Stalls similar to that for Single Stalls shown at Fig. 170 may be adopted.

The great objection to these methods of working is in the formation of detached pieces of goaf, which afterwards cause injury to the stumps of coal left between them. With detached goaves there cannot be uniformity in the breaking of the top, a point which should be always aimed at in pillar

working. For the most part these methods are adopted on the house-coal seams at moderate depths from the surface.

A very important modification of the Double Stall System is in operation at the Celynen Colliery, Abercarne, Monmouthshire, which will now be described.

The Colliery has been working since about 1878, and is the deepest in the Abercarne Valley. The pits are two in number, both being sunk 354 yards to the Black Vein, and are 80 yards distant from each other. The upcast is circular in shape, the diameter being 18 feet, whilst the downcast is elliptical, the axes being 22 and 18 feet. The downcast only is used as a winding shaft. A pair of 38-inch diameter cylinders are used for winding, and these have a 6-foot stroke and are fitted with Cornish valves. Flat wire-ropes are used, the drums being 16 feet in diameter. A single-decked cage carries two trams in the shaft, each of which holds 28 cwts. of coal. The daily output in 1881 was 1,300 tons on the average. A Waddle Fan is used for the ventilation, the upcast being used for no other purpose than ventilation. The fan is 45 feet in diameter, measures 2 feet 4 inches wide at the tips, 4 feet 5 inches at the nave, the ear being 13 feet in diameter. In 1881 it was being driven at 52 revolutions per minute, discharging 220,000 cubic feet of air per minute at a water gauge of 3·5 inches. Two return air-ways led to the upcast shaft, one having an area of 90 and the other of 100 square feet. The velocity of air in the one was 1,000 and in the other 1,300 feet per minute. Mueseler safety-lamps were used throughout the mine, in consequence of the large amount of inflammable gas emitted from the seam worked.

Fig. 172 shows a section of the Black Vein at this Colliery, and the plan Fig. 173 shows the method of working. Three levels are driven from the shaft, each being 9 feet wide. Between the central or main level and the upper is a distance of 33 yards, and a distance of 27 yards separates it from the lower. A series of pairs of headings are driven to the full rise out of these levels, at regular intervals. These pairs of headings are separated from each other by about 115 yards of solid coal, when first driven. The headings are 9 feet wide, having a 27-yard pillar between those forming a pair. When driven forward a distance of 275 yards above the upper of the three shaft-levels they are stopped, double road stalls being turned on either side, one out of each heading, and at the top or far end of it. A face of 12 yards is taken out in these stalls, the two roads being formed one on the rise side next the solid and one on the low side next the pillar of coal. The roads are 6 feet wide, the 8 yards between them being gobbed with the rubbish. The two roads are turned narrow off the heading for 6 yards, are then joined, and the face of 12 yards carried on. Three stalls separated by 12 yards of coal are driven off each heading at a time, and carried forward for a distance of 55 yards. On reaching that distance the pillar is worked back in a manner similar to that shown in Fig. 171, 6 yards of coal is taken back from above and a similar distance from below the road till within 8 yards of the heading, the stump being left to support the roof next the heading. Another batch of three stalls is started from each heading at a point lower down or nearer the main level, and these are ready to work the pillars back when the other three are finished.

This is repeated until the coal is all worked to within 30 yards of the upper of the shaft-levels. The stumps and the pillars between the headings are then taken out. The headings are then stowed up in order to isolate the goaf here formed from the other workings.

A thin seam of coal exists 10 fathoms above the Black Vein, and it was

Scale 3 Chains to 1 Inch

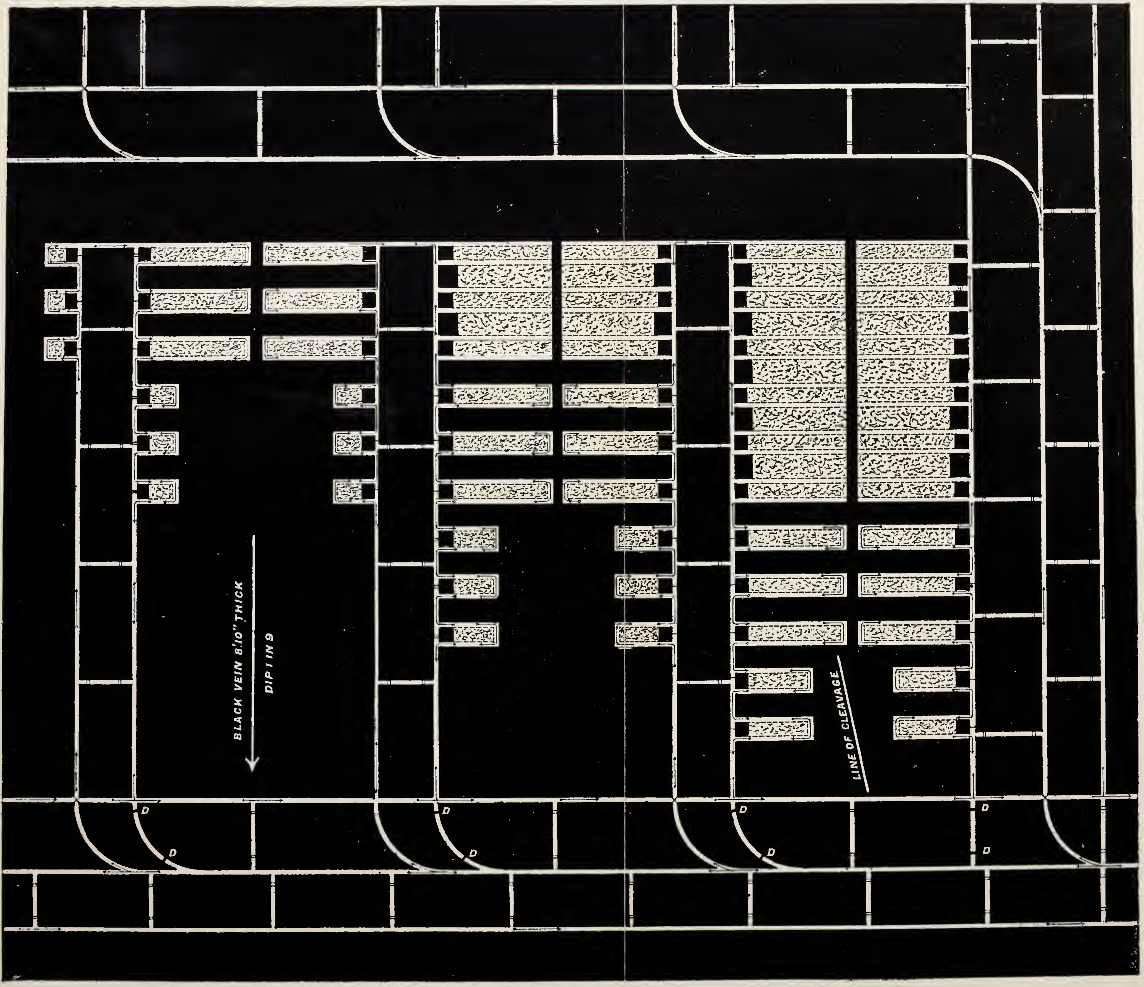


Fig. 173.—Celynen Colliery, South Wales. Double Stall Method of Working.

[To face p. 174.

proposed in 1881 to sink pits from this thin seam to the goaves and so drain off the gas.

The stalls in the next pair of headings are driven in exactly the same way as the last, so that when the headings are finished and stowed up, there is a rib of coal 5 yards in width separating the goaf formed in one pair of headings from that formed in another. This rib is lost. Pairs of levels, parallel to the shaft levels, and on the rise side of them, are driven at intervals of 315 yards, so as to

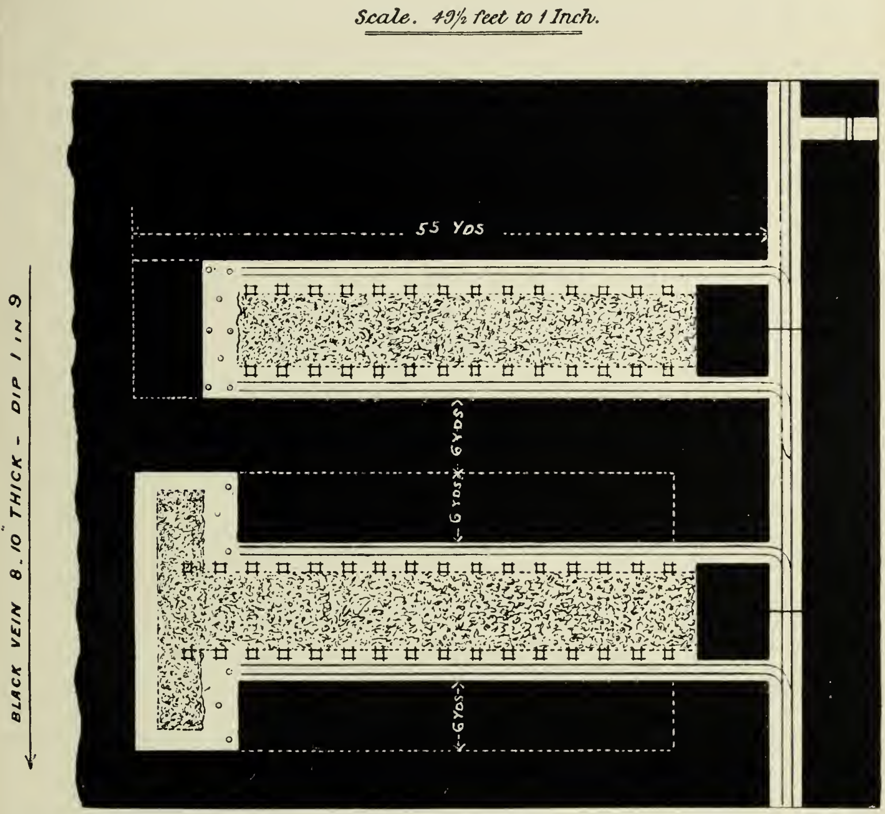


Fig. 174.—Arrangement of the Broken in the Double Stall Workings on the Black Vein at Celynen Colliery.

leave a barrier of coal 40 yards thick between the upper end of the headings and the next level above. The same system of headings and stalls is driven from the other levels above. After the levels have reached the boundary and the coal is worked out from all the headings, the pillars between them are worked back.

Fig. 174 is an enlarged plan showing two stalls, as worked at Celynen, and is designed to indicate more clearly the details of working the stalls forward and the pillars backward, with the timber, &c. used in the operation.

The props and collars used are notched in the Welsh style (see Figs. 155 and 156), and these sets of timber, not shown on the drawing (for clearness), are placed at intervals of from 3 to 6 feet along the road from the heading and the tram rails

run between each pair of props. On the waste side of the road, cogs are placed at intervals of 6 feet, and these are shown on the plan Fig. 174. Between the cogs, old props are stretched horizontally and are laid so as to protect the road from falls of small coal and rubbish from the waste. The cogs are built of old props and are from 2 to 3 feet square, being filled up with small coal in the centre. Any bad roof between the cogs is secured by props having lids. The roof is supported along the face by a line of props 6 feet apart, another row having first been placed behind and three feet from the other row.

The props are 10 inches in diameter, are set with their thick end upward, and the lids over them consist of old props. Wherever the roof or coal falls close to the face small stumps of coal are left to support the roof. The small coal made in the working is gobbed, the roof gradually settling down over it. No attempt is made to recover the props supporting the roof along the face, when driving the stall forward. In bringing the pillar back on either side of the stall, however, the props at the face, and the sets of timber and cogs in the road are taken out, and if, as is often the case, a bad roof necessitates the top coal being left for a roof in driving the stall forward, a considerable portion of this coal is got in working the pillars backward. The props, sets of timber, and chocks in the stalls are all set by the collier, and he also draws all that are afterwards recovered, receiving 1*d.* a prop for doing so. The custom is for the colliers to pack the stall-roads behind them when bringing back the pillars. Four men here work in a stall in each shift and they get about 3 tons of coal each in the shift. In bringing the pillars back they divide into two companies, each two men having 6 yards of face in returning. In 1881, the colliers were paid 1*s.* 6*d.* for large and $5\frac{3}{4}d.$ per ton for small, and these prices included propping, cogging, and stowing. For that portion of the roads driven narrow from the heading, they were paid 1*s.* 11*d.* per yard, but no yardage was paid after the two roads were joined and the place opened. The colliers do not require to hole under the coal; the stalls are shorn on both sides and the coal comes off in slabs.

The 5 feet 6 inches of coal under the top coal is not so good as that above it. Where the roof is sound enough to admit of it, the top coal is worked and 2 feet of bottom coal left on, except in the roads. When this is done, 4 inches of inferior roof coal is left on and there are lids put on the head-pieces, not extending from one head-piece to another, but projecting or overhanging equally on either side of the head-piece which supports it. In all other respects the working is the same as when the top coal is left on.

There is no regulation in force as to the distances between props and sets of timber on the main roads, but there is an understanding that these are not to be greater than 4 feet, and they are placed closer together where required.

The sets have the Welsh notch, the props and collars are 8 in. or 9 in. thick. The height of the roads to the inside of the collar is 7 feet, the width at the top is 6 feet and at the bottom $10\frac{1}{2}$ feet. The object of this form of timbering is to resist the side pressure, which at the depth of the workings is very great.

A considerable amount of cover lies over the coal where worked, for although the shafts are only 354 yards deep the workings go immediately under the mountains and have as much as 700 yards of cover.

A special class of men timber the main roads, and these work during the day time. Two men work together, and in 1881 were paid 1*s.* 8*d.* a set of 9-foot timber, and in addition they received 1*s.* 6*d.* per ton for the coal taken down from the roof. The cost for timbering at this Colliery was 9*d.* a ton on large

coal and 7*d.* per ton if reckoned on the gross output. The price paid for timber at the Colliery was 23*s.* 6*d.* per ton.

At Risca Colliery, near Newport, also in Monmouthshire, the same seam, viz., the Black Vein, is worked by Longwall.

The Colliery began working in the same year as Celynen, and in 1880 an explosion occurred here. An upcast and a downcast shaft, each 17½ feet in diameter, are sunk to a depth of 284 yards, at which depth the Black Vein is reached. The downcast is used as a winding shaft, having single-decked cages. The cages carry two trams, one in front of the other, each holding about 18 cwt. of coal. In 1881, the average daily output was 1,200 tons, the day consisting of 16 hours. The shaft is fitted with six wire rope conductors, two of which pass through guides on the outside of each cage, and two in the middle, between the

Scale. 12 Feet to 1 Inch.

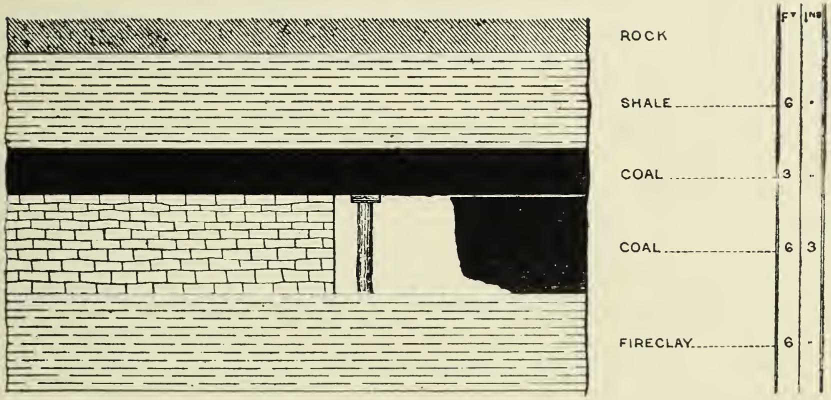


Fig. 175.—Section of the Black Vein at Risca Colliery.

cages. The last two prevent the cages from touching each other. As they pass at meetings there is only the thickness of the rope between the cages. A pumping-engine lifts from 600 to 700 gallons of water per minute in this shaft, the water coming from old workings to the rise. The other pit is used only for ventilation, which is caused by a Guibal fan 40 feet in diameter. In 1881 a ventilating current of 180,000 cubic feet passed through the workings with a 3·5-inch water-gauge. The velocity of the current in the main air-way was 20 feet per second.

The Black Vein here has not the same dip as at the Celynen Colliery. There it is 1 in 9; at Risca the seam is generally flat, but in some parts it dips 1 in 14.

The pits are sunk in a valley, but the workings run under mountains and thus have a cover of about 500 yards.

Two shifts of men are employed, one working from 6 A.M. and ceasing at 2 P.M., the other beginning at 2 P.M. and stopping at 10 P.M. The 8-hour period between 10 P.M. and 6 A.M. is used as a repairing shift.

Fig. 175 shows a section of the Black Vein at the Risca Colliery. The shale given in the section as 6 feet varies in thickness through the pit. Sometimes there is none and the rock forms the roof over the coal, at others the shale is 20 yards thick. Below the 6 feet of soft Fireclay shown as forming the thill or floor in the section, is a harder bed of fireclay. Whichever bed is used for a floor

the pressure causes it to rise in the road. The top coal of 3 ft. is left on for a roof.

Fig. 176 shows the method of working. The stall-roads are only 9 yards apart, and are cut off by cross roads at about every 50 yards. The roadsides are faced with stone brought down from the surface at a cost of 1*s.* per ton. The goaf spaces between the walls thus made are filled with small

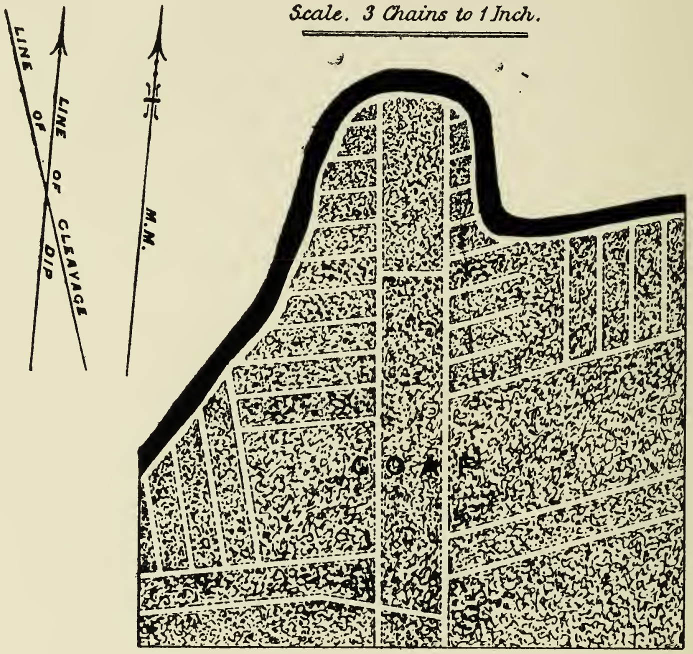


Fig. 176.—Risca Colliery, near Newport, Monmouthshire. Plan showing Longwall Method of Working the Black Vein.

coal, and stones and rubbish, obtained from the repairing of roads. The collier puts in props where required, there being no rule to fix the distances between them.

None of the props along the face are recovered, because the seam is fiery. If the props were taken out, holes would be left in the roof in which the gas would collect. In the roads 10-inch props with lids are put in about a yard apart, but those for securing the faces are from 5 to 6 inches in diameter. Two men and a boy work together in each stall, and can send out from 9 to 10 tons of coal in their 8-hour shift. In 1881 they were paid 1*s.* 6*d.* a ton for large hand-filled coal; they take charge of the stall and the roadway for 40 yards back. The line of cleavage is shown on the plan, Fig. 176, the cleavage planes being very distinctly marked. This renders the coal somewhat easy to work, as the coal comes off in large pieces, the collier merely lifting these with his pick. No holing is required under the coal unless in very exceptional circumstances.

The top coal left on makes a good roof near the face, but at a distance of 150 yards back, the full subsidence has taken place, and it becomes necessary to take down this top coal in the roads to make height. This ripping of the top is followed by sets of timber, which are notched in the Welsh method, as they are fixed in the road. The pressure on the sides of the road is very great. Larch

and French timber are used for the sets, 10 inches in diameter, and placed about every 3 feet—though this distance is subject to alteration to meet the requirements of the case. At the crossings of roads square timbers or frames are used. These consist of a usual set of timber being first fixed across both sides of the openings. Collars are then stretched between their collars and neatly notched into them, so as to form a frame. As at Celynen, a special class of men do the timbering, but here they work during the night from 10 to 6, the wages being in 1881, 4*s.* 6*d.* and 5*s.* a shift. Very few chocks are used, an occasional one being put in by the colliers at the corners of buildings, and where this is done, they are paid 1*s.* for each chock.

The timber is drawn out of the roads when they are abandoned, the roads being stowed up tight as the timber is drawn out in going backwards. The material for stowing these roads is got from the falls which are frequently taking place in the different roads.

The side pressure is so great that ordinary brick arching will not stand it. A weak point in the main road is secured by having strong stone walls built against

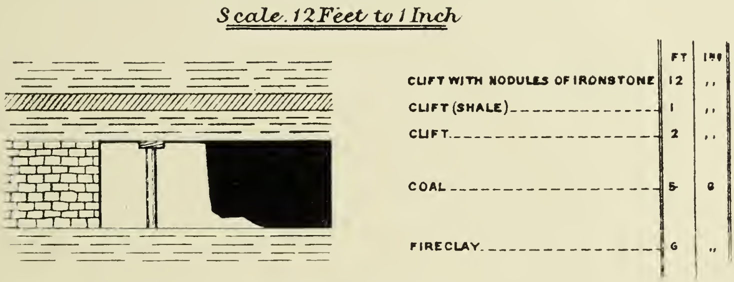


Fig. 177.—Cwmpark Pit, Ocean Collieries, Treorky, South Wales. Section of Four Feet Steam Coal.

the sides, and having strong oak beams stretched across between them. The cost for timber is 5*d.* per ton on the output, the price paid for pit timber at the colliery being 21*s.* per ton. The roads are dry and dusty, and are watered. The firemen look after the ventilation and visit each place twice during the 8-hour shift.

The method of working the steam coals in the Rhondda Valley, South Wales, is by Longwall. The Ocean Collieries comprise five coal-drawing and five upcast shafts, all working the Smokeless Steam Coal.

The Cwmpark Pits, situated at Treorky, are 200 yards deep to the 4 feet Steam Coal, one being a downcast, the other an upcast. The upcast is used only as a ventilating shaft, and has a furnace at the bottom of it. The downcast is the winding shaft. The cages are single-decked and carry one tram each. The tram holds 2 tons of coal, and is made of iron, the curved sides being of sheet-iron, and having two cross-bars at each end. The body of the tram is placed within the wheels, which run loose on the axles, and the axles loose in the guides or carriages under the tram. The gauge of way is 3 feet. The coal is large, and is piled up 3 feet above the sides of the trams. In the underground engine plane the rails are flat-bottomed, and weigh 40 lbs. to the yard; those in the roads to the faces, 22 lbs.

Fig. 177 shows a section of the seam worked, which lies very flat. The 2 feet of clift next the coal is ripped down in the roads at the faces, and built into the waste. The collier does this ripping, and keeps the face of it within a foot or two of the face of the coal.

In the cross roads the second bed of clift above the coal is taken down, and

also in the stall roads, when they get too low, and this is also built into the waste. The material from the ripping together with the small coal are sufficient to nearly fill the waste.

Fig. 178 shows the method of working adopted. The stall roads are 12 yards apart, and these are cut off by cross roads or headings every 50 yards.

Props and lids are used at the face, the lids being made of split props. A row is placed 3 feet back from the face and parallel to it, the props being set 6 feet apart.

Three-foot chocks are placed at the corners of buildings in both the stalls and the headings. The stall roads are secured by props and lids—6-inch props

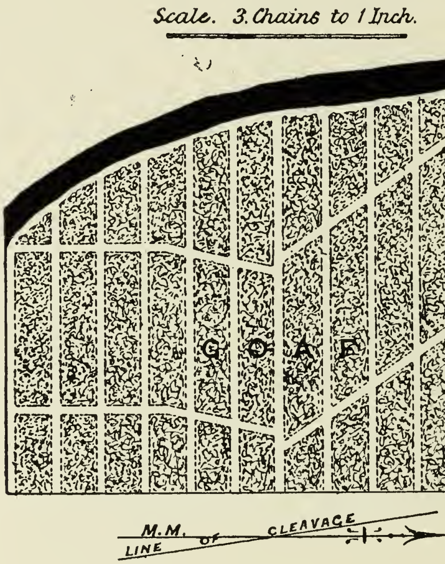


Fig. 178.—Ocean Colliery, Treorky, South Wales. Plan showing Longwall Method of Working the Steam Coal Seams.

being used. Frequently they require no timbering. No rule is in force as to the distance between props; the collier puts these where he considers they are required. The roof is good, being subject only to occasional slips.

Chocks or cogs are built along each side of the headings, at the corners of the buildings forming the stall roads, and also between them; the chocks on one side of the road are placed not opposite those on the other, but so as to break band with them. The chocks are 3 feet long, and old round timber is used for them. They are filled inside with rubbish.

In the headings, all the timber, props, and chocks are put in by the collier, who is paid according to a recognized scale for doing so. In 1881, the tonnage price of screened coal paid the collier for hewing, filling, and setting props was 1*s.* 7*d.*

Two men worked in each stall, getting about 6 tons of coal a day and putting it in large pieces in the tram at the stall road end. For any heading chocks put in by the collier he received 1*s.* 11*d.* each; for drawing any timber 1*d.* per prop; for ripping 1*d.* per yard per inch in height, the width being not less than 5 feet in the top of ripping, the road being 10 feet wide at the bottom. For the first ripping of 2 feet thick he received 2*s.* per yard for the necessary width. In the main roads sets of timber are used, but are not placed at any stated distance apart.

In the headings these sets are put at intervals of 4 feet. The timber used in the sets is 11 inches in diameter and notched in the Welsh fashion. The "set" timbering is done along with the second ripping by the repairers, who work at night. The price paid these men is *2s.* for each set of 9-foot timber, and they are paid extra for ripping the headings. One fireman is placed in each district of about 40 or 50 places. His duty is to attend to the ventilation in his district, to put up wooden or canvas doors where required, or to place air tubes for ventilation. Timber at the colliery costs about *24s.* per ton, or about *11d.* a cubic foot. As an example of the amount of subsidence of the roof, it may be mentioned that a road, driven through stowing which had been standing for a year and a half and 150 yards back from the face, was found to be only 3 feet 4 inches high, so that the subsidence from the face to that point 150 yards distant was from $5\frac{1}{2}$ feet to 3 feet 4 inches, nearly 40 per cent. of the original height.

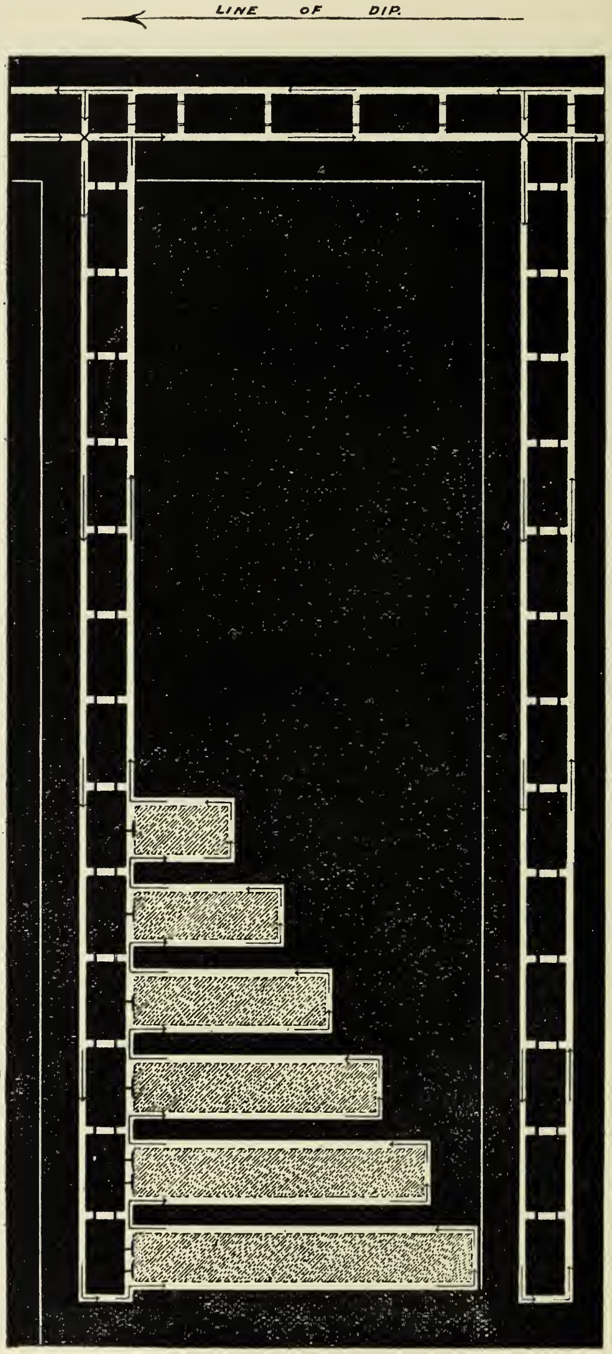
In North Wales a system of working called the Wicket system is applied to seams of from 6 to 10 feet thick where the inclination is slight and the quantity of firedamp yielded is not great. Fig. 179 shows this method.

A pair of drivings proceed to the full rise and out of them are turned at right angles pairs of levels. A distance of about 130 yards separates one pair of levels from another and they are carried forward about 400 yards. The roads are driven 9 feet wide, and the two forming a pair are separated by 13 yards of coal. They are connected at intervals of 27 yards by cross holings. The coal formed between any two pairs of levels is worked out by juds or sections of the whole block proceeding to the rise from the lower pair of levels. These juds are carried much like the South Wales double stall roads, a road being formed on each side of the jud and the space between packed as closely as the available material will allow. Where no suitable material is yielded in working the seam and only the small coal is available for filling the waste, the ventilating current cannot properly be kept round the face owing to the imperfectly packed waste. The 7-yard rib of coal between the juds is not worked, so that much loss arises from working in this way.

In 1857, the Bank System of working prevailed in South Yorkshire, where the Barnsley Seam yields various qualities of coal from its several beds.* Very little of any other seam was at that time worked in South Yorkshire. The seam varies in thickness. Near its outcrop and 5 miles from the town of Barnsley the seam is divided into many thin beds, the divisions being formed by fireclay partings of several inches thick. Proceeding southwards, many of these fireclay partings disappear, and at one mile to the north of Barnsley, the seam presents the following section :

	ft.	in.	ft.	in.
Coal, called "Day Bed"			1	0
Parting	0	2		
Coal, called "Middle Bed"			1	1
Coal, called "Low Bed"			1	3
Parting	0	8		
Coal and Pyrites, called "Clay seam"			0	7
Coal, called "Hards"			2	8
Coal, do. "Slottings"			2	2
Total thickness of Coal			8	9

* See Lectures delivered at the Bristol Mining School, 1857.



Scale. 3 Chains to 1 Inch.

Fig. 179.—Plan showing the Wicket System of Working Coal in North Wales.

This is a highly prized section of the seam, and as in this state it lay within 150 yards of the surface, it was extensively worked in earlier years. Proceeding southwards to a mile south of Barnsley, the top coal, called the "Day Bed," is absent from the seam, and its other portions are so much thinner that the total thickness of coal in the whole seam is only 6 feet 6 inches. In the South Yorkshire Collieries, there is little or no parting in the seam, the average section of which is—

	ft.	in.
Soft Coal (Middle Bed)	1	5
Soft Coal (Low Bed)	1	6
Coal and Pyrites (Clay Seam)	0	6
Hard Coal (Hards)	2	5
Soft Coal (Slottings)	2	4
Total thickness	8	2

The "Day" and "Low" beds at the top and the "Slottings" at the bottom are filled and sold together as gas and household coal, the "Hards" (being the best part of the seam) is to some extent made into coke, but is mostly used as a steam coal, for which it is well adapted. The "Clay" seam is inferior, owing to the iron pyrites mixed with the coal, and is sold for lime and brick burning, or stowed in the waste.

The Barnsley seam contains much inflammable gas. When the working places are driven across the cleavage, the gas is emitted freely from the planes of cleavage, but where places are driven in line with the cleavage no gas is given off beyond that which comes from the coal actually obtained in such working places. In both cases the gas comes from the coal, only in the first case it is drained from the solid on either side of the working place. This remarkable peculiarity arises from the compact nature of the coal and the regularity of the cleavage planes which run without communication with each other.

In designing the Bank System of working, in which pairs of bordgates or winning places are driven to the full rise of the seam and across the cleavage, in advance of the main workings, it was thought that the gas would be drained or drawn off from the blocks of coal extending from one pair of bordgates to another, and experience has proved it to be so.

The Barnsley Seam is very free from water. Under it is a bed of fireclay from 3 feet 6 inches to 5 feet thick, and this fireclay contains large quantities of inflammable gas in bags or cavities. When the workings have reached the edge of these cavities, the pressure of the gas has been observed first to heave the floor up at different points along the face for many yards, this lifting of the floor being succeeded by large fractures in it (the line of fracture being more or less clear and parallel to the face of the place) through which the gas has issued with great force, accompanied by a sound similar to that made by high-pressure steam escaping from boilers.

A sudden yield of inflammable gas in this way is called an *outburst*, and has probably caused many of the unfortunate explosions which have occurred in South Yorkshire.

The Lundhill Colliery, near Barnsley, has belonged to the same Company since 1854, and in 1857, when the explosion occurred there, the Barnsley seam was worked on the Bank System, as shown on the plan, Fig. 180.

The lowest is the main or horse level, being driven on both sides from the bottom of the downcast, which is the winding shaft. The level to the rise is called the middle level, and the upper the bank level. All three levels are driven abreast of each other, and are separated by 20 or 25 yards of coal. Openings

connect these levels at intervals of 30 to 40 yards. At a suitable distance from the downcast shaft a bordgate, 6 feet wide, is driven towards the full rise, to the bank level. Here another bordgate is started as a companion to the first, being separated by 8 yards of coal. This pair of bordgates advance abreast of each other, and are connected by openings through the coal at every 20 yards. When the three levels have advanced 110 yards, another pair of bordgates is driven out of them similar to the first pair. In the centre of the block of coal left between the two pairs of bordgates a leading bank, 18 yards wide, is started from the bank level and is worked towards the rise. In the meantime the bordgates have advanced sufficiently, viz. 40 yards from bank level, to allow of slits being driven level course out of the bordgates towards the approaching leading bank. When the slits are holed into the bank (one on each side) they become the roads through which the coals are conveyed from the face. "Following-up-banks" are now commenced at the bank level, and consist of a face of 6 yards from the sides of the leading bank. These "following-up-banks," one on either side of the leading bank, are carried up to the slit above, and, as the leading bank has been progressing, it has now holed into the second pair of slits. Afterwards the "following-up-banks" are continued forward and second ones started from the bank level, taking another portion of coal 6 yards wide from that left. This operation is repeated as each leading bank reaches the slits, until the coal between the goaf and bordgates has been reduced as much as may be deemed safe or advisable.

In each of the 110-yard blocks along the level, the bordgates and banks are repeated in the same order as before described, and are carried forward to any required distance. In order to maintain a passage for the air and travelling road down each side of the goaf formed by the leading bank, packs 5 feet wide, and 6 feet from the coal rib are built with the blue metal which is allowed to fall behind the face of the bank. Another pack of similar size is carried up the centre of the leading bank, and these three packs are built and carried on as the face advances. Each following-up-bank builds one pack as it advances, 6 feet from the ribside, so as to maintain a roadway. All the packs in course of time are overthrown by falls in the goaf, except those at the side, which must be kept to maintain the air-way. The pillars left in driving the bordgates, that is, those formed in each pair, and any coal it may have been deemed prudent to leave next the bordgates, are worked at the last when the banks have been worked out. This pillar coal is first worked at the highest and inside point and worked backwards.

In working the coal the holing was done in the "slottings," the hard coal above it being then wedged down. The clay seam was carefully separated from the rest, and the low bed of soft coal taken down. The timbering was placed under the top bed of softs; as the face advanced, the subsidence of the roof caused the top soft coal to fall at the goaf side of the props and was filled into the trams.

The air was taken from the downcast to the extremity of the level, doors being placed in all the working bordgates. From the face of the levels it was carried up the inside pair of bordgates, around the face of the new leading bank, up the next bordgate to the face, returning to the slit leading into the next bank. Here the air divided as it entered the bank, a small portion descending the air-way maintained by the pack-wall to the following-up-bank on that side and returned by the middle level to the other side of the bank, ascended the air-way corresponding to the one it descended on the other side, and joined the current, which had traversed the leading bank face, at the highest holed slit. The united volume passed along the slit to the next pair of bordgates, where it ascended the one, returning along the other to the highest slit, dividing, as before, at the first bankgate. Here a division took place, one portion descending to air the following-up-banks on that side and passing into the middle level. The main current, after passing the leading bank and descending to the highest slit, again divided, giving

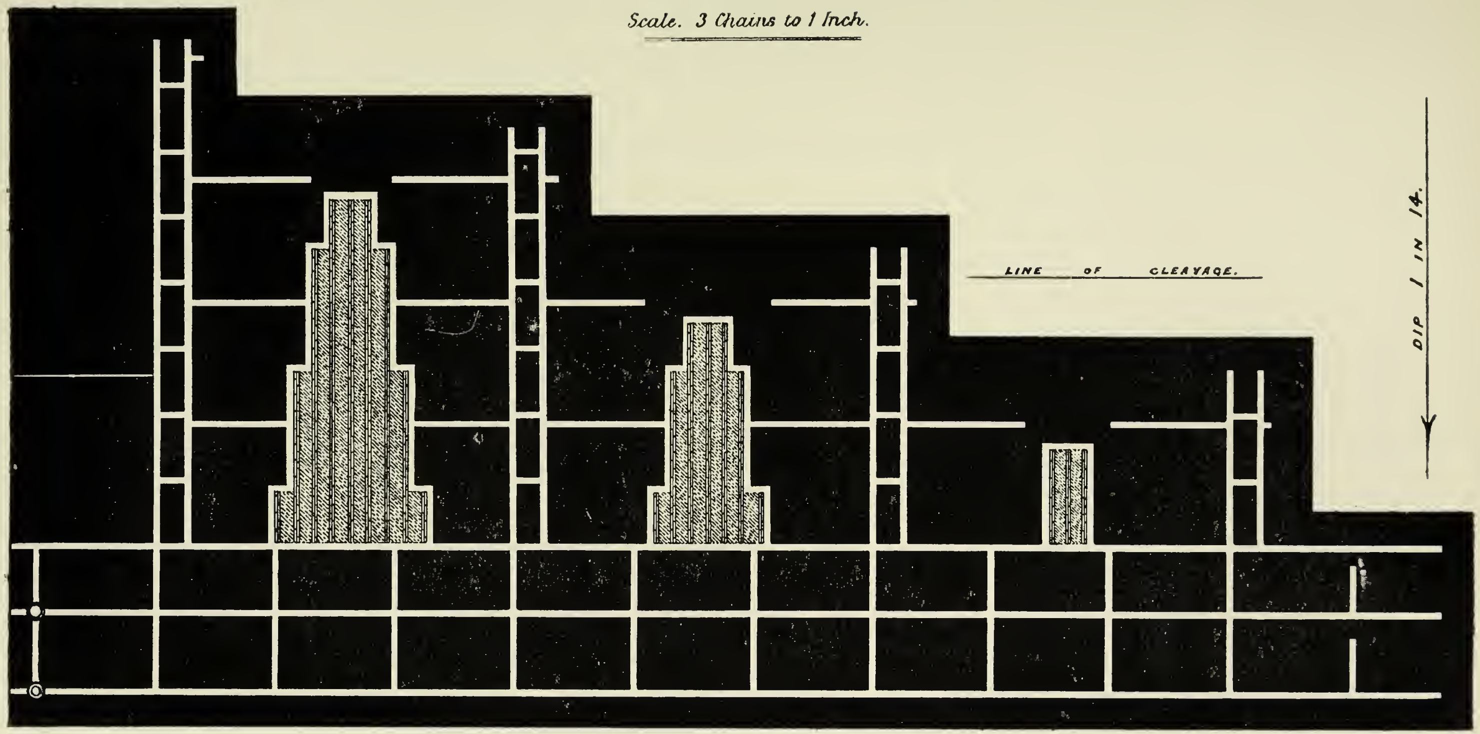


Fig. 180.—Plan showing the Bank System of Working the Barnsley Seam in Operation at the Lundhill Colliery, Yorkshire, in 1857.

off a split to ventilate the following-up-banks below. This current joined that which had aired the following-up-banks on the other side in the middle level, and the two currents passed on up the next bordgate to join the main current at the highest holed slit; these re-combined currents passed into the first pair of bordgates from the shaft, by one of which it descended to the upcast shaft.

It will thus be seen that whatever advantage was obtained from draining the gas into the bordgates was quite neutralised by these ventilating arrangements. The air, after traversing the bordgates, would become charged with the gas emitted there, after which it was passed to the workmen at the face of the banks.

The Lundhill pits are 210 yards deep to the Barnsley Seam, and prove the following seams:—

Melton Field .	4	feet	thick	at	40	yards	from the	surface.
Abdy	3	,,	,,	,,	70	,,	,,	,,
Kents Thin . .	2	,,	,,	,,	106	,,	,,	,,
Kents Thick .	3	,,	,,	,,	144	,,	,,	,,
Barnsley Seam .	8	,,	,,	,,	210	,,	,,	,,

Under the town of Barnsley the next coal seam of importance below the Barnsley Bed is the Swallow-Wood Coal, 60 yards below; the next is the Flockton, 140 yards lower. The Parkgate is 80 yards below the Flockton, after which

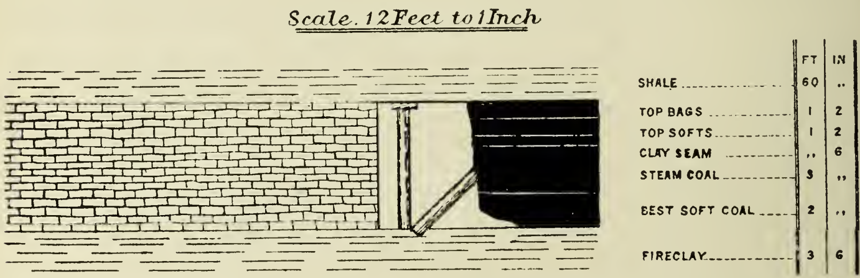


Fig. 181.—Lundhill Colliery, near Barnsley. Mode of Spragging and Propping in the Pillar Workings of the Barnsley Seam.

comes the Thorncliffe Thin, 35 yards still lower. Next in descending order is the celebrated Silkstone Seam, 52 yards below the Thorncliffe Thin, but none of these seams approach the thickness of the Barnsley Bed.

The Bank System of working has now given place to the Bord and Pillar. In 1881 the operations at Lundhill were confined to three shafts, one being used solely as a ventilation pit. All are circular shafts, the two downcasts being 11 feet 6 inches and 12 feet in diameter respectively, and the upcast 14 feet 6 inches. A pair of horizontal high-pressure winding engines, 25-inch diameter cylinders, 5-foot stroke, and 14 feet 6 inch drum, winds coal at one of the downcasts, and a similar engine at the other. Together they raise 750 tons in one shift of 9½ hours. A furnace, having a grate surface of 144 square feet, placed at the bottom of the upcast shaft, produces the ventilation. The quantity of air passing up the upcast is 300,000 cubic feet per minute. This air is not passed over the furnace, but enters the upcast shaft by means of a dumb drift 35 yards from the bottom. The total volume of 300,000 cubic feet includes 50,000 cubic feet of air used to ventilate the stables and feed the furnaces.

Fig. 181 shows a section of the Barnsley seam taken in 1881, from which it is seen that the coal has a total thickness of 7 feet 10 inches.

The method of working now adopted is shown on the plan, Fig. 182, and is an arrangement of Bord and Pillar. The pillars are 40 yards square, and the roads

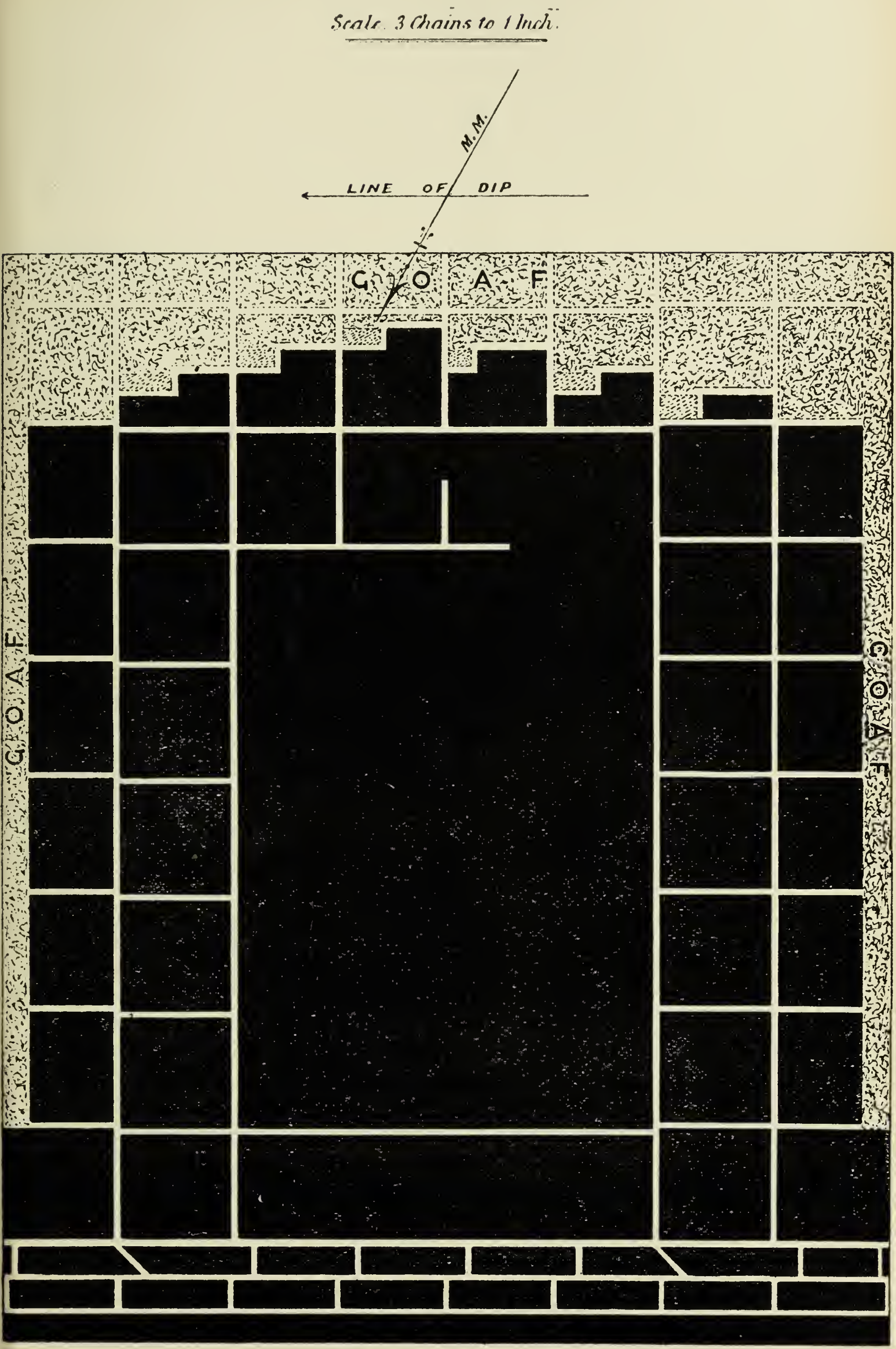


Fig. 182.—Lundhill Colliery, near Barnsley. Plan showing Bord and Pillar System in Operation for Working the Barnsley Seam.

about them, both "bords" and "endings," are of a uniform width of 6 feet. Pairs of levels are driven from the main-dip roads. A block of coal 150 yards wide separates the different pairs of levels. After these levels have reached a given distance, this 150-yard block is broken up into the 40-yard square pillars, and worked back. There is this peculiarity in it, however, that only one line of pillars is formed in advance of the line of broken. The "endings" are not quite opposite, but one is 3 feet inside the other, to enable the rails to be turned into the working face on either side. The workings are dry and the roads slightly dusty, and are therefore regularly watered. No timbering is required usually in the roads, as the top coal is left on and forms a good roof. Below the fireclay shown on the section are 7 yards of sandstone. The "Top Bags" are left on to support the roof, but are afterwards taken down in the pillar working.

Except for carrying the brattice, no props are used as a rule in the whole workings. The brattice is made of wood, in lengths of 10 feet, and 4 feet broad, overlapping in the centre and nailed to slight posts. The practice is to divide the

Scale. 12 Feet to 1 Inch

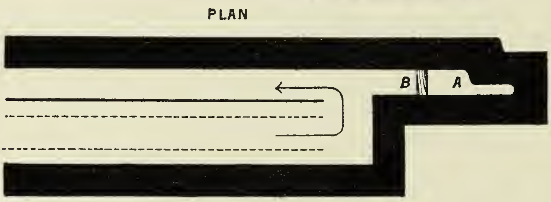


Fig. 183.

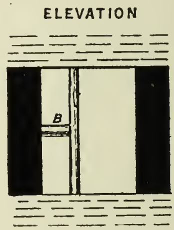


Fig. 184.

LUNDHILL COLLIERY. WORKING IN THE SOLID PLACES OF THE BARNSLEY SEAM.

road into an intake on the dip side, 4 feet wide, and a return 2 feet wide on the rise side. Two men work together in a place, advancing in the solid—a holer and a filler.

The holer cuts a shearing, A (see sketches, Figs. 183 and 184), 6 inches wide, about 18 inches from the rise side of the place. When this shearing is in 3 feet or other suitable distance, he wedges off the 18 inches of coal, B (see sketches), on the rise side, and is thus enabled to extend his shearing further in, whilst the filler holes and works off the coal in the 4 feet width on the low side of the road. The holer places a sprag where shown on the sketches to protect both himself while shearing and the filler whilst holing. The shearing is kept 9 or 10 feet in advance, that portion of it which is 2 feet wide being 3 feet behind the face of the shearing.

The men driving one of these solid places received 5*s.* per yard, and 11*s.* 11*d.* for 10 tons of coal sent out.

Fig. 185 shows the method of working the broken, and is an enlarged plan of one of the pillars shown in Fig. 182. The juds are 8 yards wide, and are usually carried up to the rise the whole length of the pillar. Occasionally, if more coal is wanted, it is obtained by men commencing on the other side of the pillar, and working downhill to meet the jud coming up.

Fig. 185 shows one jud of a pillar as being worked off, and another in the act of being driven. The roadway is formed along the coal to one side of the lift, and is 6 feet wide. On the waste side of the road a pack-wall, 6 feet wide at the bottom and 5 feet at the top, is built with the 6 inches of clay-seam and debris from the waste. The face is protected by two rows of posts besides the pack-wall, the rows being 3 feet apart, the rear row breaking band with the front row. The props are set 6 feet apart in the rows and are 6 inches in diameter, the lids

over them being of hard wood 8 inches square, by 2 inches thick. The pack-wall is added to every 3 feet, when the rear row of props is drawn and advanced to the front, where they are again set. After the withdrawal of the rear row of props, the top coal falls, and as much of it as can be removed is taken. Two colliers work in a lift. They hew and fill the coal, keeping separate the various qualities, and fix the props, receiving 11*s*. 11*d*. per score of 10 tons for so doing.

They hole 3 feet in under the coal, a foot high in front and put sprags in every 6 feet. (See Fig. 181.)

On finishing the holing and knocking out the sprags, the coal comes down. No powder is used in the solid or broken mine. Hand riddles having a $\frac{3}{4}$-inch mesh are used, the coals passing through the riddles together with the small is

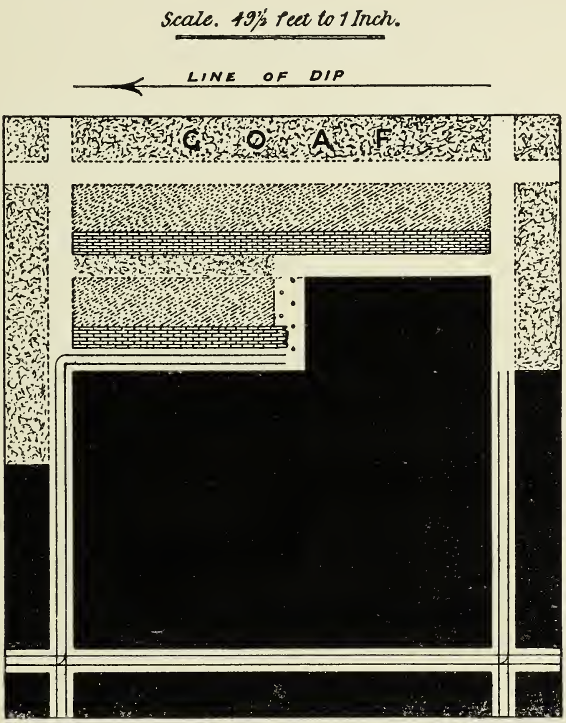


Fig. 185.—Lundhill Colliery, near Barnsley. Mode of Working off Pillars in the Barnsley Seam.

thrown into the waste. The colliers at the face do not build the packs; a special class of day-men called packers do this, and also draw the props. These men are paid 4*s*. 4*d*. per day. In drawing props a "dog" (see Fig. 137) is used. This "dog" and the method of using it have been described in the chapter devoted to Timbering and Walling. When the props have been drawn the roof falls quickly, but the pack-wall maintains the roadway without any kind of timber being placed under the roof of top coal. Occasionally the men at the face work the coal and build the pack-wall, and where this is done, the men receive 3½*d*. a ton beyond the usual score price. The top coal everywhere makes an excellent roof, both in the roads and faces, and the shale over the coal is not exposed anywhere except in the waste.

The advantage of this system over the Bank system previously adopted is manifest. The broken does not follow closely behind the exploring places, but the latter are carried to their destination, leaving large blocks between them, and when these blocks are worked, it is from the inside backwards, leaving the goaf behind.

It is true, that no amount of ventilation can dilute and render harmless such volumes of gas as are given off at the outbursts above mentioned, and it is probable they will occur, in every mode of working: still, the method adopted should give the greatest possible margin of safety. The practice of getting the coal without the use of powder at Lundhill increases the margin of safety.

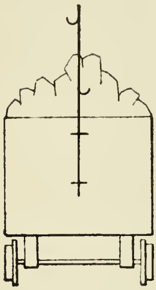


Fig. 186.—Kiveton Park Colliery. Double Fork for Endless Rope Haulage.

At the Kiveton Park Colliery, near Sheffield, the Barnsley Seam is worked by the Longwall system. The colliery has been working coal since about 1867, the furthest workings being about $1\frac{1}{2}$ miles from the shaft.

The colliery consists of two shafts sunk 400 yards to the Barnsley seam. One of the shafts is a downcast and the other an upcast, each being 13 feet in diameter.

Only the downcast is used for winding, and for that purpose it is fitted with wire-rope guides and double-decked cages.

About 1,100 tons are landed in one shift of 10 hours, by means of a pair of horizontal high-pressure engines, 36-inch cylinders, with 6-foot stroke. A furnace produces the ventilation in the other shaft, which is fitted with rope guides, so that

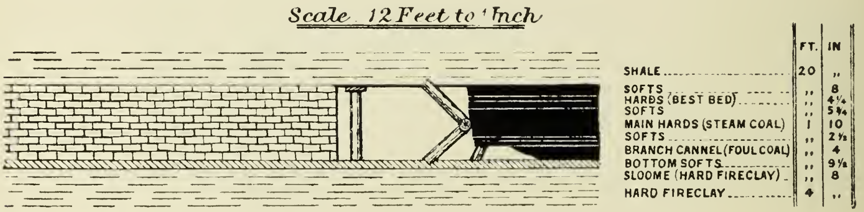


Fig. 187.—Kiveton Park Colliery, near Sheffield. Sprags and "Cockermegs" in the Barnsley Seam.

in cases of emergency, the workmen may be raised in it, but no coals are wound. An endless rope for driving the underground haulage, is taken down this shaft and passed round one of Fowler's clip pulleys at the shaft bottom. This pulley is on an upright shaft, as also are two other pulleys of the same description worked by clutches, driving endless ropes to different districts.

The tubs are loaded above the sides, and that they may be drawn along the engine planes, double forks are fixed into the ends of the tubs. By this means when the tub is loaded high, the rope rests in the higher catch of the fork, when empty, in the lower catch. See Fig. 186.

Fig. 187 shows a section of the seam, which is here 5 feet 4 inches thick, the coal being a little harder than at Lundhill, and used chiefly as a steam coal. Above the coal is 20 feet of strong bind, 2 feet of which is ripped down in the roads. Above this is a bed of black rock 6 feet thick. The thill under the coal consists of hard "clunch" or fireclay, and underneath this is "bind" (shale).

The seam dips to the East, the inclination being 1 in 22. Fig. 188 shows

the method of working, which is by Longwall with the roads advancing to the rise.

One of the roads, most suitable for the purpose, is made a "jinney," or self-acting incline, and levels from it cut off the roads going to the rise every 200 yards. The distance between the stall roads is 60 yards. At each road-head iron plates are placed, and rails for the tubs laid along the face. The tubs are "spragged" in being taken down the road leading to the incline. In a 60-yard stall two stall-men work. They are small contractors, and receive a tonnage price on all coal sent from the stall and delivered at the top of the "jinney."

They employ other men in the stall. The contractors do the packing, the timbering, and the ripping at the stall roads.

The system of building pack-walls next the roads and in the waste is similar to that at High Park, shown in Fig. 191, and described later on.

The ripping in the roads yields material for building the packs at the sides of the road, which is 10 feet wide. These packs are made 6 feet wide, and others parallel to them are built in the waste of the material yielded in the holing and fallen stones. The face is protected by two rows of 6-inch timber, carried along the face behind the rails. The rows are 6 feet apart and a similar distance separates any two props in the rows. As the pack-walls are built, the rear row of props is taken down, and re-set in advance of the other row. As the props are drawn, the roof in the waste falls. Although the stall-men have entire charge of the place, they must build the pack-walls and place the props as directed by the deputy. Commencing at the road-head, these men hole along both sides to the extremities of their stall. They hole 5 feet under the coal, the height of the holing in front being 18 inches. Sprags are put in under the coal 6 feet apart as the holing proceeds. See Fig. 187. Where the coal is tender, besides the sprags, "Cockermegs" are put in. These consist of a sloping prop reaching from the floor, and another reaching from the roof which hold a third prop placed horizontally along the face. See Fig. 187. When the holing all along the coal is completed, and held in position by the sprags, a cut or shearing is made in it at the road-head, after which one or two sprags are taken out, thus allowing a portion of the coal to fall. As this coal is removed in the tubs, other sprags are taken out, and more coal taken down. This process is continued along the stall on both sides of the road until the extremities are reached, the rails being laid forward as the coal is taken down in front. After a holer has worked to the end of his "bank," he returns to the road-head, and there begins another holing at the point from which the coal has just been removed.

The stall-men have two fillers, and one holer, so that 5 men work in a 60-yard stall, from which they send out daily from 20 to 25 tons of coal. No timber is used in the roads, the roof being excellent. The timber for the face costs 2*d.* to 2½*d.* a ton.

At the High Park Colliery, Langley Mills, Notts, the Barnsley seam is called the Top Hard Coal and is worked by Longwall. The colliery has been working since about 1861, the Top Hard seam being won by two shafts at a depth of 200 yards. These are both downcast and winding shafts, one engine hauling coals from both. Each shaft is 10 feet in diameter, and carries only one cage. Two trams, each holding 11 cwt. are placed in each cage. About 900 tons a day are landed, all the coal being picked and lifted from the trams into the waggons by hand, and no screens used. The upcast shaft is 12 feet in diameter and 116 yards deep, it being situated 1,100 yards away (on the rise side of the measures) from the downcast shafts. Near it, is another upcast shaft for a separate colliery. Each upcast has a Waddle fan 30 feet in diameter, so placed that, should one ventilator break down, the other can be used to draw the air from both shafts.

The fans run 70 revolutions per minute.

Scale. 3 Chains to 1 Inch.

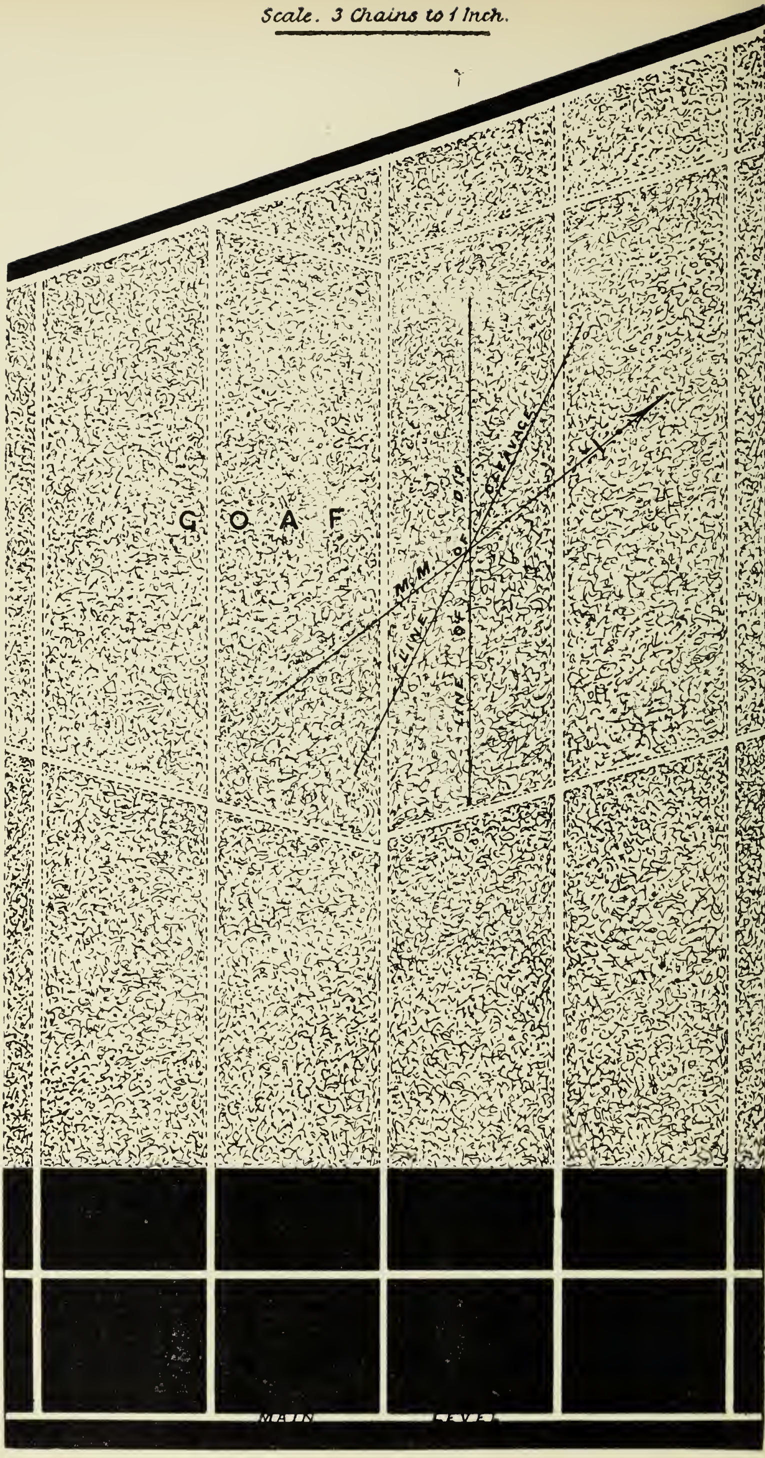


Fig. 188.—Kiveton Park Colliery, near Sheffield. Plan showing Longwall Method of Working the Barnsley Seam.

Fig. 189 shows a section of the Top Hard Coal Seam, and the mode of propping and spragging at the face.

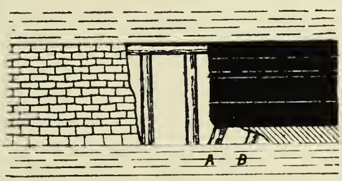
The seam is 5 feet 2 inches thick, the dip being 1 in 22.

Over the seam are 15 feet of shale, 3 feet of which next the coal are taken down in the roads. Above the shale is a bed of coal 2 feet 6 inches thick, and over this is "bind" or shale. The thill is composed of fireclay 2 feet thick, and below it is a dark sandstone.

Fig. 190 is a plan showing the method of working. In 1881 there were 48 stalls all in line for the daily output of 900 tons. The distance from centre to centre of the gate-roads is 50 yards. These are carried to the rise, and are cut off every 400 yards by a cross-cut from one of the rise roads, which is made into a "jinney" or self-acting incline. All the coals are sent down the "jinney."

Three men have charge of each stall, and they at the date named had a contract price of 1*s*. 9*d*. per ton for hand-filled coal, all the small being gobbed. The contractors employ loaders and holers, themselves doing other kind of work necessary in the place, including the first ripping of 3 feet in the gate-road, building the packs

Scale. 12 Feet to 1 Inch



	FT.	IN.
SHALE	15	,,
SOFT HOUSE COAL	1	,,
RIFLER	,,	10
MINGE	,,	4
MAIN HARD COAL	1	7
INFERIOR COAL	1	5
HARD FIRECLAY	1	,,
FIRECLAY	2	,,

Fig. 189.—High Park Colliery, Langley Mills, Notts. Mode of Propping and Spragging Coal in the Top Hard Coal Seam.

and drawing the coal out to the first pass-bye, which never exceeds a distance of 50 yards from the face. From this pass-bye the coals are drawn by a pony to the top of the incline, and after being let down the incline reach the shaft by a rope haulage.

Fig. 191 shows the practice of building the packs, and timbering at the face. When a holing is begun at the road-head, the packs are within 4 feet of the face, and there is a row of 8-inch props along the face, there being spaces of 4 feet 6 inches between the props. Norway timber props are used, 5 feet 3 inches long, the lids over them being 12 ins. × 4 × 6, made from broken posts. The stall-men set these props. The place being as described, the holers do their work from the road-head along both sides to the extremities of the stall. As they proceed, sprags (A, Fig, 189) 2 feet long are placed every 6 feet. Where required short sprags (B, Fig. 189), are put in under the coal. They are about 15 inches long, and are fixed at irregular distances apart. The holing is carried 4 feet in, the stall-men paying the holer 1*s*. 6*d*. for a fathom in length of such holing. The holing rates are 1*s*. a fathom for 3 feet in, 1*s*. 6*d*. a fathom 4 feet in, and 2*s*. a fathom for 5 feet. The practice here, however, is for the holer to hole 4 feet in, and after this has stood a short time to allow the fireclay to become crushed, the stall-man himself holes the other foot in. When the holing is completed, and the coal kept securely up by the sprags, a cut or shearing, 2 feet wide at the outside and tapering to 3 inches about 5 feet in, is made at the road-head. The stall-man then takes out 3 or 4 sprags, which allows the coal they supported to fall. This is filled into the trams, the roadway being carried along the face, as shown at Fig. 191. Props and sets of timber are placed over the rails at intervals of 4 feet 6 inches. One end of the collar is let into the coal 3 or 4 inches, the other end being supported by a prop. The props vary from 6 to 8 inches in diameter,

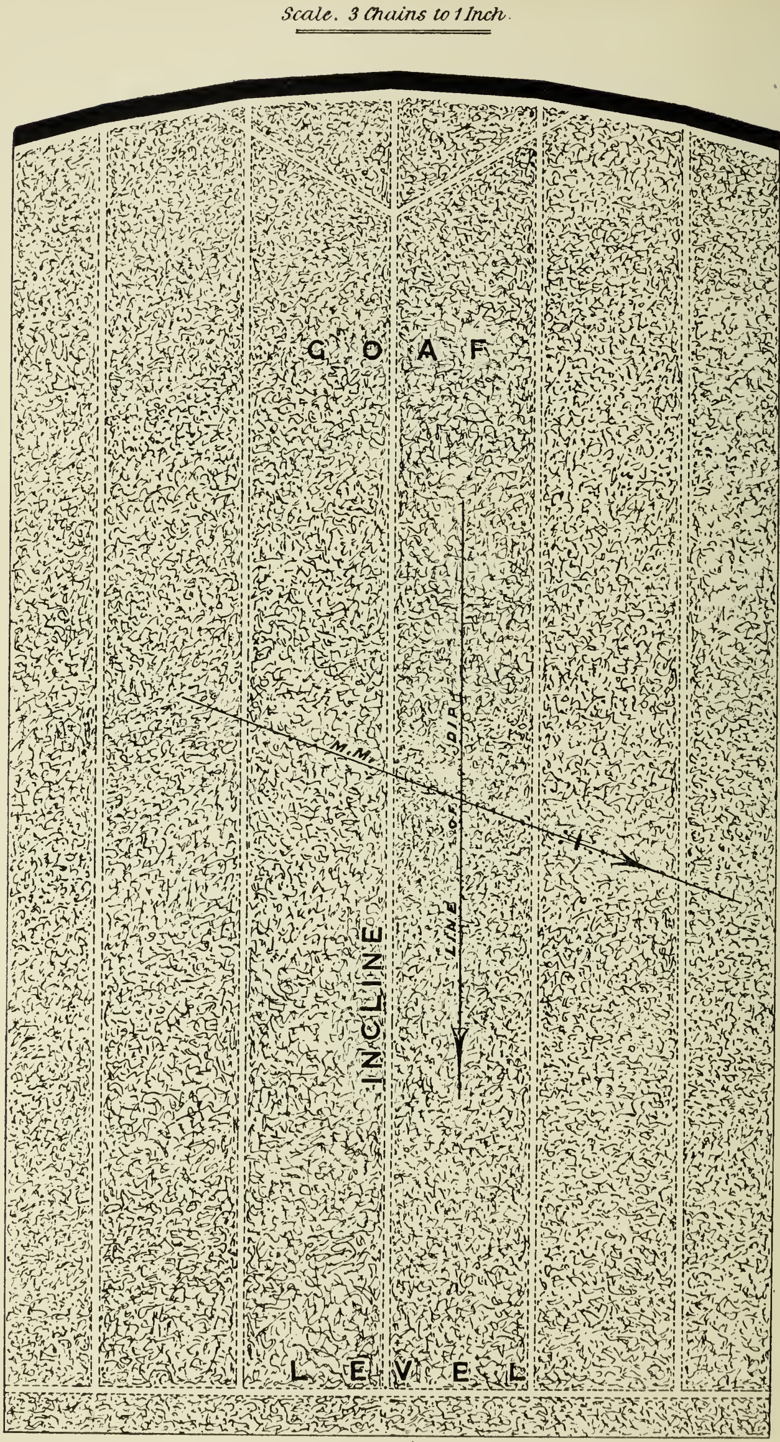


Fig. 190.—High Park Colliery, Langley Mills, Notts. Plan showing Longwall Workings in the Top Hard Coal Seam.

and are about 5 feet 3 inches long. The collars are 4 feet long and 5 inches by 4 inches in section. Having removed the coal first got, other sprags are taken out, allowing another portion of coal to fall, which in its turn is filled into the trams and removed, this process being continued until the end of the stall has been reached on both sides. Before commencing to add a fresh portion of building to the packs there are 2 rows of props about 5 feet apart behind the props, and sets of timber over the roadway. The stall-man draws these props as he builds the packs. The roof in places is tender and much broken, and where this is so the packs are built of the debris from the roof, about 6 feet wide, with intervals of 9 feet between them. The ripping of the road yields material for packing at the sides.

The duties of the deputies in the pit are much the same as that of the firemen in other districts. They superintend the stall-men, examine the places for firedamp,

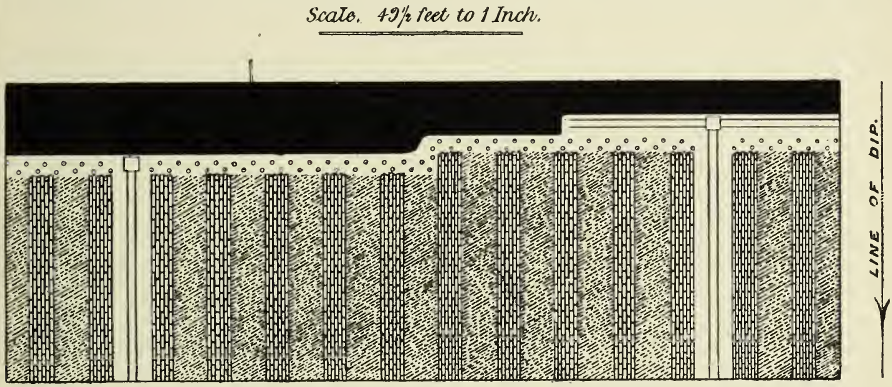


Fig. 191.—High Park Colliery, Langley Mills, Notts. Plan showing part of two Stalls with the packwalls, in the Top Hard Coal Seam.

attend to the ventilation, &c.; but, subject to this superintendence, the stall-men set up and draw out all the timber, and rip the roads. Naked lights are used in the workings, but a safety lamp is fixed in the highest part of the ripping, so as to give warning in case any firedamp appears. Powder is used in ripping the roads.

Very few props are used in the main roads, as the latter sink quickly, and in the main levels this necessitates ripping up to the 2 feet 6 inches of coal, which makes a good roof. The extreme subsidence takes place at a point 50 yards back from the face. The roads being dusty are watered, but not regularly.

The method of working the Maudlin Seam, Wearmouth Colliery, Sunderland, is by Pillar and Stall. The colliery has been working coal since 1835, but sinking operations were commenced there in 1826. There are two shafts, an upcast 11 feet 6 inches in diameter, and the downcast 12 feet. Both are winding shafts, and together in 1881 they raised 2,000 tons a day, the day here consisting of 24 hours. The tubs used carry 8 cwt. each. Two 4-decked cages run in each shaft. Two tubs are placed in each deck, so that the cage carries 8 tubs. The furnace which helps to produce the ventilation is not placed at the bottom of the upcast, but in the Maudlin Seam, 44 yards from the bottom. It has a firegrate area of 144 square feet, and is greatly assisted by the furnaces of 6 boilers. The total quantity of air varies from 180,000 cubic feet per minute to 200,000 cubic feet, being highest in the winter months, when the natural ventilation is greatest.

The shafts prove the Maudlin and Hutton seams at a depth of 530 yards and 574 yards respectively, both seams being worked. They lie almost flat, the dip to the East being so slight as to cause no inconvenience in carrying roads in any direction. The working faces in most of the districts are from 2 to $3\frac{1}{2}$ miles distant from the shaft, and the coals are brought out along engine planes. The tail-rope system of haulage is adopted, and there are more than 20 miles of steel-wire rope in daily use in the pits. In one of the longest engine planes, where the empty train is taken in at the same time that the loaded one is brought out, there are 126 tubs on the road at one time.

A section of the Maudlin Seam is shown at Fig. 192.

The openings in the coal are 12 feet and 9 feet wide, the pillars left being 40 yards square. No holing under the coal requires to be made by the workmen, as the coal is tender, and the workmen "scallop" it, that is, they hack it out with picks while standing upright. In the screens used the bars are an inch apart,

Gears in working place.
Fig. 192.

Gears in main road.
Fig. 193.

METHODS OF TIMBERING IN THE MAUDLIN SEAM, WEARMOUTH COLLIERY, SUNDERLAND.

and 55 per cent. of the coal got passes through the screens. There is no objection to this, as the coal is used for gas making. The colliers do not place their own timber at the working faces. This is done by the deputies, unless in cases of emergency, when the collier puts up timber, which is left in his place for the purpose. In the solid working, sets of timber are placed in the roads every 3 feet. The props are $3\frac{1}{2}$ inches in diameter, 6 feet high, 5 feet 6 inches apart at the bottom, and 4 feet 6 inches apart at the top, as shown at Fig. 192. The rails are laid in the centre of the roads between the two upright props. The collars are made of 5-inch props split through the middle, and the half-round side is placed next the roof.

The props are put in by the deputies as the places are being driven, and remain in until another end is through. The deputies then draw them, after which the roof usually falls to a height of 2 or 3 feet; but sometimes the fall is sufficient to fill the place up. The pillars crumble off at the sides, owing to the tender nature of the coal.

The Broken is worked by splitting the pillars, and bringing back the jud on both sides. A deputy attends about 12 men, and they send out about 60 tons a day.

The collier receives 10*d.* a ton for hewing and filling, in the whole mine.

The roof over the coal is good, the cost for timbering being $1\frac{1}{4}$*d.* per ton in the roads and solid places, and 2*d.* in the pillar working.

The main roads are timbered, as they require it, with props, or sets of timber. At some parts the sets are placed 3 feet apart, and are 6 inches square and 9 feet long. The props in the main roads are $4\frac{1}{2}$ inches in diameter, 8 feet long,

and have hard wood lids 6 inches × 7 × 2½. Where the sides are good one side of the collar is notched 6 inches into the roof, and receives support on the other from a short prop 3 feet long, this prop being placed in a notch prepared for it in the roof over the coal, see Fig. 193. The timbering of the main roads is done by a special class of men called stone-men. They work in pairs, and receive about 1*s*. for a 9-foot "balk" or collar, but the price varies according to the difficulty of the task in fixing it. Two stone-men working together can put in 10 sets of 9-foot timber in a shift.

The workings are dry generally, although a little water is found in some of the swamps, and this water is very salt, containing as much as 21 ozs. of salt to the gallon. The roads get very dusty; they are watered regularly, and the dust cleared up once a fortnight.

At the Silksworth Colliery, near Sunderland, the same seams are worked as at Wearmouth Colliery. Silksworth Colliery is comparatively new, and consists of two shafts, one of which is 16 feet 6 inches in diameter, and the other 14 feet. Both shafts are sunk to the Hutton Seam, at a depth of 580 yards, the Maudlin being passed at a depth of 540 yards. 2,000 tons of coal are landed daily. Only the larger shaft is used for winding, and it is fitted up with 4 cages. Two of these wind coals from the Hutton, and two from the Maudlin Seams. There are two pairs of winding engines, each having 48-inch cylinders and 6-foot stroke. The engines winding from the Maudlin Seam have 25-foot cylindrical drums; the other pair of engines, winding from the Hutton Seam, have a scroll drum 13 to 28 feet in diameter. One pair of engines was made by Barclay of Kilmarnock, and the other by the Grange Iron Co., Durham. Both are fitted with a very simple and effective automatic variable expansion gear. Mr. Daglish, the chief viewer, in a paper read before the North of England Institute of Mining Engineers, has fully described this expansion gear. The cages are arranged as at Wearmouth Colliery to have 8 tubs on 4 decks, but are here loaded and unloaded at two levels, both at the surface and underground. The smaller shaft is used only as an upcast. A furnace is placed in the Maudlin Seam which has 90 square feet area of firegrate. The total quantity of air passing up the shaft is 195,000 cubic feet per minute. This reaches the shaft by three main returns, one 100 feet area, passing 45,000 cubic feet a minute; one 124 square feet, passing 80,000 cubic feet a minute; and that in the Hutton Seam, 100 feet area, passing 70,000 cubic feet. The dip is not uniform throughout the workings, varying from 1 in 18 to 1 in 6.

The following is a section of the Maudlin Seam:—

	ft.	in.
Blue Metal (Roof)	1	8
Coal	5	8
Sagger (Fireclay)	0	2
Bottom Coal	0	10
Sagger	0	8
Coal	1	6
Blue Metal	3	0

The method of working is by Pillar and Stall, the pillars being formed 50 yards square, the openings round them being 12 feet one way, and 8 feet the other. The 12-foot wide places are commenced 8 feet wide, and after going in 9 feet they are widened to their full width, and are carried on so till they are nearly through. When within 9 feet of being through they are reduced to a width of 8 feet, and carried to the end that width. The working is in the 5 feet 8 inches of coal in the above given section. The roof consists of a "blue metal" 20 inches thick, over which are 3 fathoms of post and blue metal mixed. Below the 5 feet

Scale. 49½ feet to 1 Inch

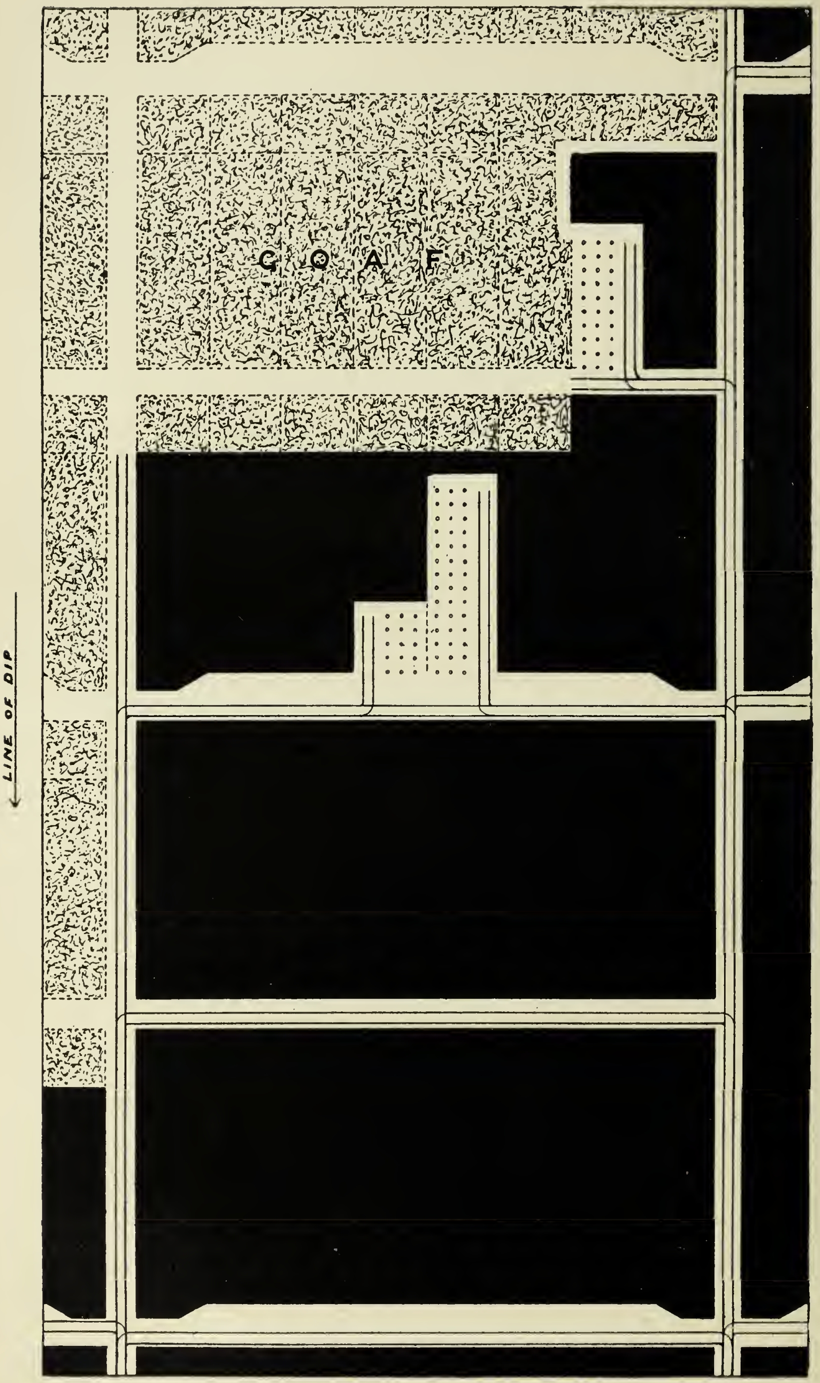


Fig. 194.—Silksworth Colliery, near Sunderland, South Durham. Plan showing the usual method of Pillar Working in the Maudlin Seam.

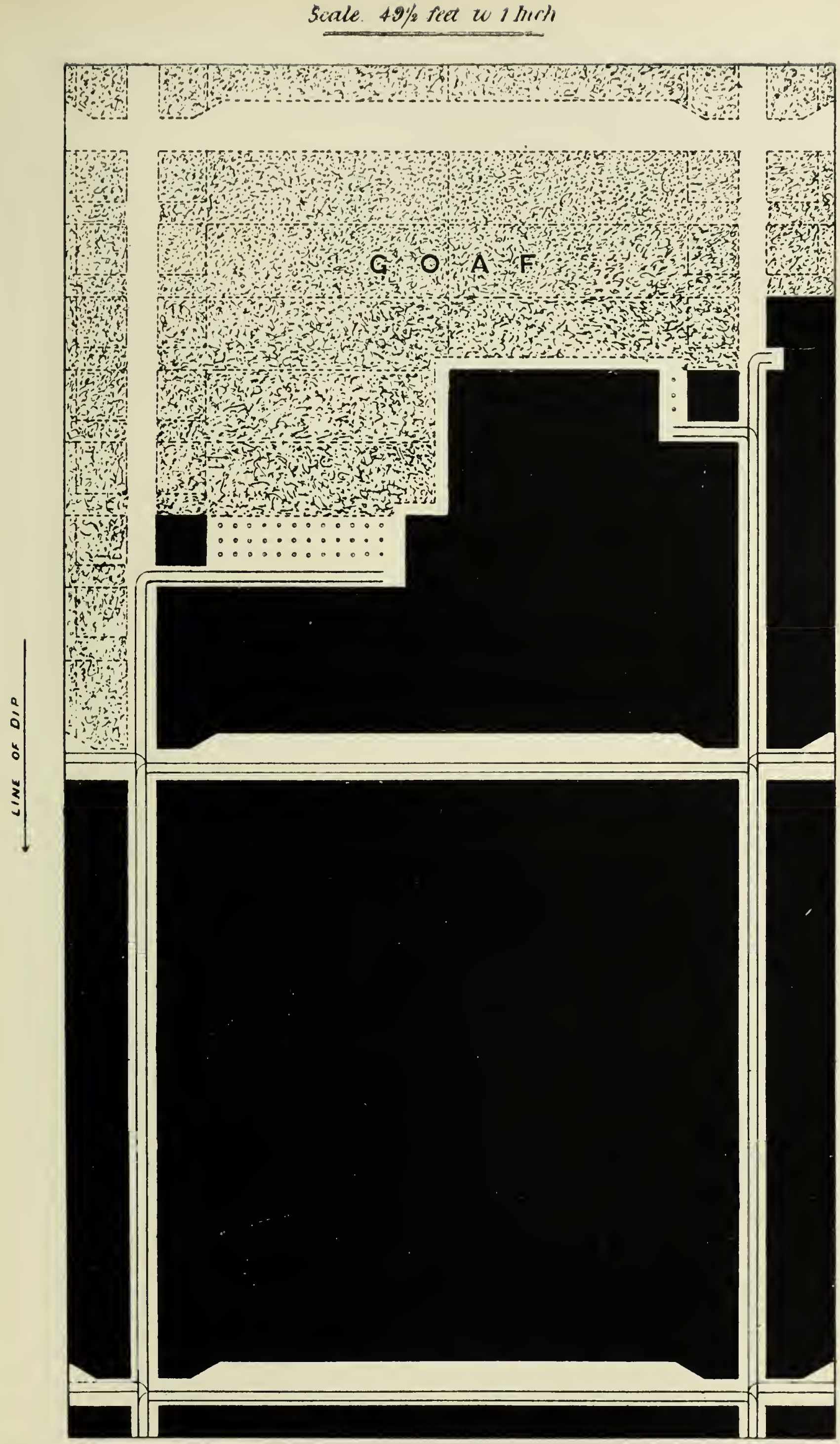


Fig. 195.—Silksworth Colliery, Sunderland, South Durham. Plan showing Pillar Working under a good roof in the Maudlin Seam.

8 inches of coal is a thin bed of sagger, then 10 inches of bottom coal, followed by 8 inches of sagger, then 18 inches of coal, all of which are taken out in the main roads to make height, but the coals are inferior and unmarketable, and so are left on in the ordinary working. Below come 3 feet of blue metal, and then 3 or 4 fathoms of sandstone. The workings of the Silksworth pit are within half-a-mile of those at Wearmouth, and although the Maudlin Seam is not quite so thick at Silksworth, the coal is very similar at both places. The main roads are timbered as at Wearmouth.

Fig. 194 shows the usual method of working the pillars at Silksworth. First the 50-yard square pillar is split by means of an 8-foot place. From this split, and also from the ending parallel to it, lifts are taken out. These lifts are 6 yards wide, and each is carried 20 yards to the rise and 5 yards to the dip. In the two lifts being driven at the low side of the pillar in Fig. 194, it is seen that the portion of 5 yards to the dip, belonging to those lifts, is not taken out. That operation would follow the completion of the rise portion of the lift. The lifts are kept "stepped."

Fig. 195 shows the practice of working the pillars at Silksworth, where the roof is good. Here the lifts are driven half-way up the pillar from both sides without splitting it. The place is commenced 6 feet wide, leaving 4 yards of solid coal between the road and the goaf, and is continued this width for a distance of 4 yards, after reaching which it is widened out to the waste. This leaves a "stook" or small pillar, of 4 yards square, between the road and the goaf. The lift is carried half-way across the pillar, or 25 yards, after which the props are drawn by the deputy, and the roof allowed to fall. Two men work in each lift in each shift, there being a fore and back shift. They are paid 8d. a ton for hewing and filling the coal. As a fact, the lifts are taken off the pillars on both sides of the split, as shown in Fig. 194, but Fig. 196 shows how they might be arranged to be worked from one side only. The workmen "scallop" the coal, there being no holing, and therefore no spragging. Props and "sets," the same as at Wearmouth, are used, the sets being arranged with the rails between them in the lifts, and placed about 18 inches apart. On the waste side of the road three rows of 6-inch props are placed about a yard apart, as shown on Figs. 194 and 195. There is no rule in force as to the distances apart these props are to be placed, but there is an understanding that they are not to be more than a yard. The deputy sets them, and when the lift is finished he draws the props out, commencing at the inside. The hewers are out of the pit when the deputies draw props. The 4-yard "stook" is then worked off and the props drawn. In cases where the deputies cannot draw the whole of the timber without assistance, timber drawers, who are always spare deputies, are put on to help them. These men receive 8*d.* and 10*d.* a score for taking out the props, but this price is paid only on whole timber, unless the broken timber is required, in which case two broken props count as one whole one. A deputy attends to 10 or 12 men, his duty being to set and draw timber for the men, and see that all the ventilating arrangements are right. He works an 8-hour shift, the same as the colliers, and during his shift visits each place twice. He receives a daily wage.

The whole-mine workings are the same as at Wearmouth. The roof over the coal is good, the cost of timber being $2\frac{1}{2}d.$ per ton.

At the Florence Colliery, Longton, North Staffordshire, the Great Row Seam is worked by the Longwall method. At this Colliery, which is quite new, two shafts prove the Great Row Seam at a depth of 352 yards. The pits are $12\frac{1}{2}$ and 14 feet in diameter, one being the downcast, the other the upcast. The downcast was sunk 746 yards to the Moss Coal, which is the best Household Coal of the series, and the sinking of the upcast to the same seam was proceeding in 1881.

The downcast is used to wind coal, for which purpose a pair of high-pressure

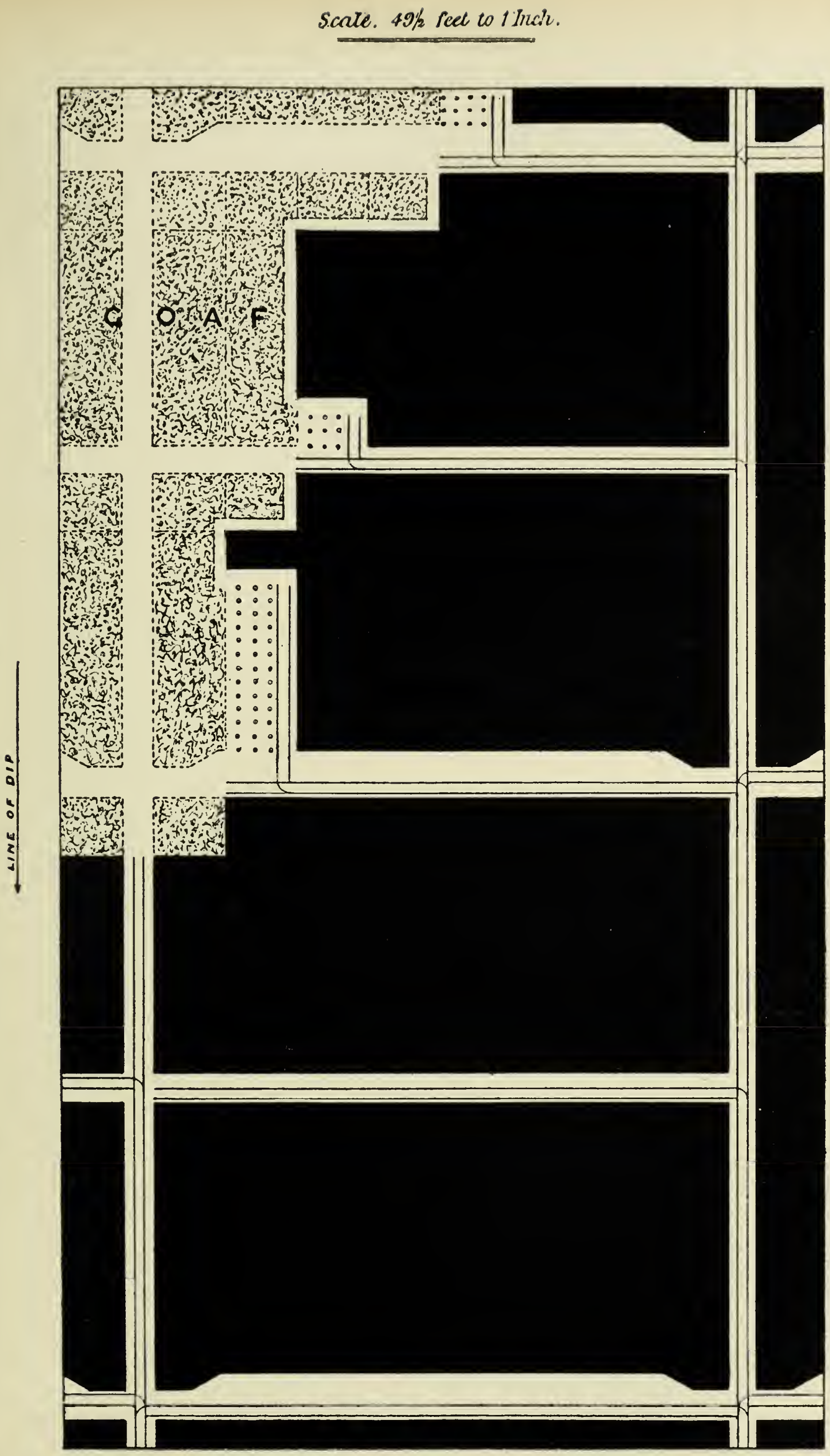


Fig. 196.—Silksworth Colliery, near Sunderland, South Durham. Plan showing a Possible Arrangement of Pillar Working from one side of the Splits, in the Maudlin Seam.

horizontal winding engines, with 42-inch cylinders, 7-foot stroke, double beat valves, and a 28-foot diameter cylindrical drum, are used. The engine is supplied with an automatic cut-off, to stop the cage when it reaches the surface. Coals are placed in the cages at levels or loading stages in the shaft, besides the bottom; these levels being at the Bassey, Chalky and Ash Seams, which are all worked above the Great Row.

In 1881 a Waddle fan, 45 feet diameter, was being erected at the upcast shaft.

Fig. 197 shows a section of the Great Row Seam, the average thickness of which at this colliery is, however, 6 feet. Over the coal are 8 feet of fireclay, and above this a bed of coal 2 feet 6 inches thick. Resting on this coal are beds of fireclay and bass (hard dark shale), 8 feet thick. Above this again come 8 feet of coal and partings, and then higher, 32 feet of "Binds, Slums, and Marls." The thill is composed of 37 feet of "Bass, Binds, and Clod."

The seam dips 1 in 7. Fig. 198 is a plan showing the method of working. From the pit bottom, for a distance of 350 yards, a pair of levels 10 yards apart were driven, and, on reaching a certain point, a "breasting" or face of coal 25

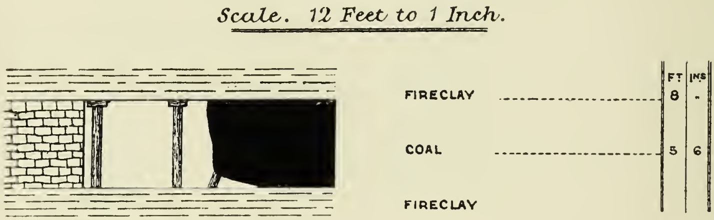


Fig. 197.—Florence Colliery, Longton, North Staffordshire. Mode of Propping and Spragging at the Working Face on the Great Row Seam.

yards wide was taken out, and a "gob" road formed in it 4 yards from the deep side-rib. The stall-roads are turned out of this gob road every 88 yards, and carried to the rise. They are cut off by a level every 120 yards. The faces are "stepped," one being 15 or 20 yards in advance of another. The coal is conveyed along the main level by horses, but a "jig," or self-acting incline works in every going stall-road, by means of which the coal is let down to the level.

For this purpose a 12-inch wheel is placed in a fork, and the end of the fork is passed through a prop at the road-head. A brake, consisting of a piece of iron, is pressed on the rim of the wheel by a handle working a dumb screw fastened to the fork. Only one tram is run at a time; each tram holds 8 cwts., and the brake is just powerful enough to stop it at any point during the run. A chain is used on the inclines, and as the face advances the wheel is easily moved forward.

The bottom level advances, taking a "breasting" or face of 25 yards. The road is 6 feet wide, and on either side of it a pack-wall, 3 yards wide, is built. The face is protected by two rows of props, which are 6 inches in diameter, the rows being placed 4 feet 6 inches apart, with a $5\frac{1}{2}$ or 6-foot space between the props. The lids used over the props consist of broken props, when there are sufficient for that purpose. Fresh building is put in every 5 feet, the rear row of props being drawn and re-set in advance. Sprags 6 feet apart are used under the coal. The space between the pack-wall and the coal on the deep-side is kept open as long as possible, but when this can only be done with difficulty, a hole is driven through the building from the road, and a fresh air-course carried on from this point. A chock of broken timber is fixed at the corner of each hole, and there is an interval of about 40 yards between these holes.

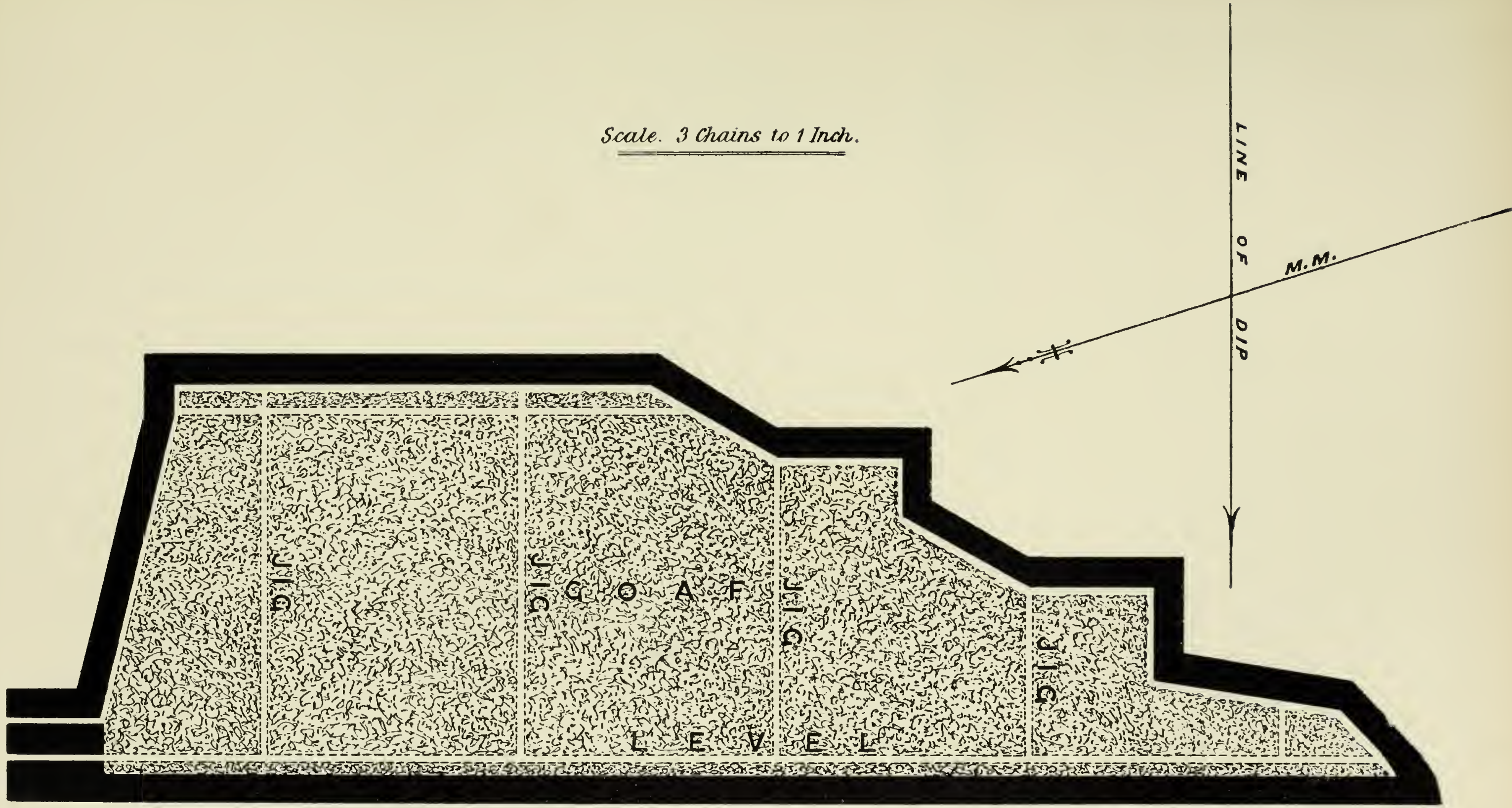


Fig. 198.—Florence Colliery, Longton, North Staffordshire. Plan showing Longwall Method of Working the Great Row Seam.

The stalls are 88 yards wide, and packs 3 yards wide are built parallel to the road (which is wide enough to admit of a double road (for the self-acting inclines) 7 yards apart all the way from one stall-road to another.

This will be seen at Fig. 199, which is an enlarged plan showing the packs, timbering, &c. The packs formed next the roads, it will be observed, are wider than those in the waste, being 4 yards. The stones obtained from the 3 feet of ripping are used to build the packs on both sides of the roads. In every 88-yard stall, are two stall-men, one for each side of the road. In their employ are 4 holers, 2 buttockers, and two packers.

The stall-men build the packs, set and draw the timber, and despatch the coals down the incline to the level, for which they receive 15*s.* per score of tubs of coal—7*s.* being allowed for slack—all of it being raised. The workmen rake the coal into iron boxes or trays 2 feet square and 6 inches deep at the one end,

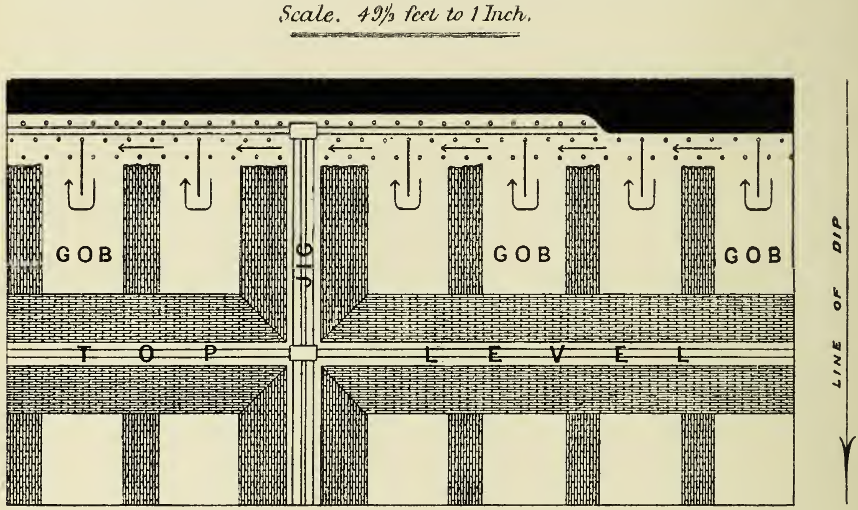


Fig. 199.—Florence Colliery, Longton, North Staffordshire. Plan of Longwall face with the Gate-road and Packwalls connected with it, in the Great Row Coal.

tapering out at the other. For carrying, these have two handles, which also enable the workman to empty the coal into the tubs conveniently. The men in one of these stalls send out during the day, or shift, 100 tubs, each of which holds 8 cwt. Besides the score price referred to, the stall-man receives 5*s.* 6*d.* a yard, for top ripping and building the road packs. Any other stones required for packs are obtained from the waste. The holing under the coal is made 4 feet in, being 2 feet high in front, the holer placing sprags under the coal every 6 feet, as shown in Fig. 197. The sprags are 2 feet long and 6 inches in diameter. The holing across the stall being finished, the sprags are knocked out; the coal is then blown down by powder. The stall-man fires the necessary shots. The coal is shot down in advance of the point where the rails are laid, but for the convenience of filling, the rails are kept very close up to the "buttock" or piece of coal, next to be blown down, and advanced as required. The holers are not obliged to remove from one side of the stall to the other, as the shots are fired, but only those working on the side where the firing takes place. After the shot is fired, they return to their work and continue as before. The props at the face are in two rows, 4 feet 6 inches apart, there being 6 feet between the props forming a row. They are from $5\frac{1}{2}$ to 6 inches in diameter at the thin end, and are put in by

the stall-man, who also draws them out, using a "dog" and chain (as previously described and shown at Fig. 137).

The pack-walls are added to every 5 feet. Where the roof is tender, a chock made of broken timber and set on small coal is put in. As shown in Fig. 199, a sheet is fixed at intervals extending from the face several feet back into the waste lying between any two of the packs, the object of which is to cause the air to travel back into the goaf. Safety lamps are used in the workings, the responsibility of examining which rests with the fireman, who superintends the stall-men, but does no timbering.

In that part of the main level now being carried in the gob, little timber is required, but in that section of it situated nearer the shaft where the pillars remain, there is great side pressure, necessitating much timber.

The sets put in consist of props 8 inches at top and 7 inches at bottom, 6 feet 6 inches long, notched with the Welsh notch (shown in Figs. 155 and 156) into an 8-inch collar, which is notched to receive the props. The sets of timber are placed from 3 to 4 feet apart. Over them, reaching from collar to collar,

Scale. 12 Feet to 1 Inch.

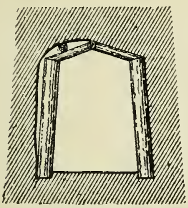


Fig. 200.

Scale. 12 Feet to 1 Inch.

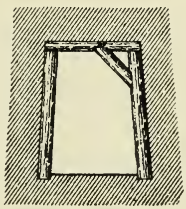


Fig. 201.

Scale. 12 Feet to 1 Inch.

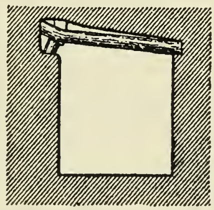


Fig. 202.

Methods of Repairing the Timber at Florence Colliery.

3-inch props are laid in the direction of the road and laggings are laid across these. Two men work together in main-road timbering, the notches having been cut before the timber is brought underground. In fixing the sets of timber, the men use an iron bar called a dog. It has prongs at both ends, and when one prop is put in place the dog is used to steady it. The other prop is then placed in its position and the collar put on. When the parts are nicely adjusted the whole is struck with a hammer. Many ingenious contrivances are practised at this colliery for repairing the sets of timber. One is a set of timber in the form of an upright "cocker," as shown at Fig. 200. The props are 5 feet 6 inches apart at the bottom, and 4 feet at the top, while the rise of the span is 8 inches. Again, where the Welsh timbering is broken, a diagonal strut is notched into the prop and the collar as shown at Fig. 201.

As a third instance of repairing, where collars have been notched into the coal without the use of upright props and afterwards broken or partly broken by the weight on them, a short strut is put up under the point of fracture and wedged tightly to the collar, as shown at Fig. 202. The roads are dusty, but as watering causes the floor to rise, it is not carried out.

The roof over the seam, although soft and loose, does not require a large quantity of timber.

At the Great Fenton Collieries, Stoke-upon-Trent, in North Staffordshire, the Great Row Coal Seam is worked on the Longwall system. It is the same seam as that worked at the Florence Colliery, last described. The colliery comprises four pits, two, named the Pender and the Bourne, having been in operation since 1876, working the Blackband Ironstone and the Great Row Coal Seam; the other

two, called the Homer and Sutherland, are sunk to the Ash Coal and Littlemine Ironstone. These two have been working since about 1880. The pits are about $\frac{1}{4}$ of a mile apart. The Pender Pit is 13 feet in diameter, the Bourne Pit 8 feet, both reaching the Great Row Coal Seam at a depth of 308 yards.

The ventilation is produced by a furnace in the Pender Pit, which is fitted with wire-rope guides, two ropes passing through the outside of each of the two cages. At meetings, there is a clearance of 15 inches between these cages. The Pender Pit winding engine has a 36-inch vertical cylinder, with a 6-foot stroke, and 20-foot drum. About 500 tons a day are landed.

The seam dips at an inclination of 1 in 10. A section of it is shown in Fig. 203. The 3 feet 6 inches of top coal is left for a roof in the roads. Immediately over it are 5 yards of moderately strong shale, above which again is a bed of coal 7 inches thick. Resting on this thin bed of coal is shale. This 7-inch bed of coal emits a large quantity of fire-damp. Forming the thill under the coal are 4 feet of hard "sagger," or fireclay, which rests on grey metal. In the Long-

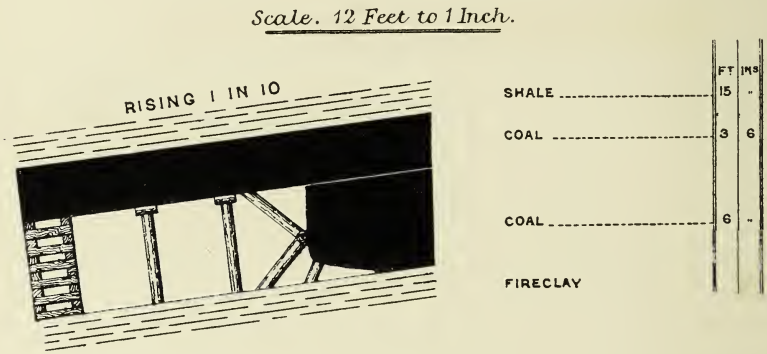


Fig. 203.—Great Fenton Collieries, Stoke-upon-Trent. Cockersprag, Sprag, Props, and Chocks at a working face in the Great Row Seam.

wall method here adopted, there are 100 yards between the gate-roads. A "Butty" contracts to put the coal into the waggons on the surface for a certain rate per ton or per score. The proprietor supplies all labour and materials. In a face of 100 yards, there are 9 or 10 holers, 4 loaders, and 2 buttockers. The buttockers break out the coal for the loaders, removing the sprags from under the coal for the purpose. There are also four packers whose duty is to build the packs. Each butty has a man specially appointed to take charge of the timber. The duties of this man are to set the chocks and draw the timber out, but the holers set all the props necessary for their safety. The holers and packers work during the night, but the fillers work in the daytime from 6 A.M. to 3 P.M., while coal is being wound in the pit.

Explosives are used to break down the coal, but no shots are fired till after 10 o'clock P.M. Fig. 204 is a plan showing the method of building the packs, timbering, &c. The roads are made 9 feet wide, and have built on both sides of them a pack-wall 4 yards wide. There are, besides these, other packs built in the waste, parallel to the roads, these packs being also 4 yards wide and separated by 8 yards of space. There is no ripping in the roads, so that stones for all the packs have to be obtained from the waste. Before commencing to hole, the cockermegs, shown in Fig. 203, are placed all along the face. They consist of two 3-foot props, and an old 6-foot prop, the latter being held in a horizontal position against the middle of the coal by the former, which are slightly notched into the roof and floor. The holing is then begun and holed 5 feet in, and as the holing

advances along the face, sprags are placed under the coal every 6 feet as shown in Fig. 203, in addition to the cockermegs already fixed. The packs are kept up within 6 feet of the face, as required by the Special Rules in force, but interposed between the packs and the face, and placed parallel with it, are set two rows of 8-inch props, having 6-foot spaces between the props, the two rows being 4 feet 6 inches apart. The rails are laid along the face between these rows. Besides this double row of props, two rows of timbering are placed between the pack-walls in the waste, these being set 6 feet apart under the top coal. Each of these rows of timbering comprises three props and a chock. The collier shears the top coal which is supported by these props, then draws the timber out, allowing the top coal to fall. He next sets props with a lid and a sill on the rubbish (see Fig. 136), thus securing the roof from which he has just taken down the top coal, and he is

Scale. 49½ feet to 1 Inch

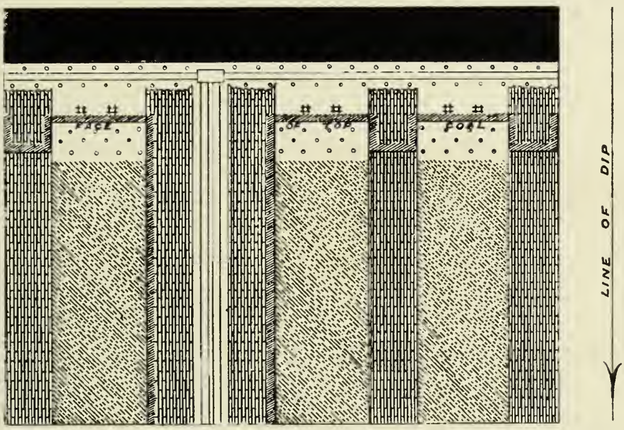


Fig. 204.—Great Fenton Collieries, Stoke-upon-Trent. Plan of Longwall face in the Great Row Coal Seam, showing Props and Chocks.

now able to work at that portion of the top coal remaining over the packs. To obtain this coal, he holes in on the 4-yard packs, for 2 yards on each side, thus allowing the coal to drop. All the coal over the packs is not got, but as much of it as it is prudent to take without running risk from the roof. The props set on the sills over the rubbish are now withdrawn with a dog and chain, by the man specially appointed for the purpose, the chocks preventing the breaking of the roof, which immediately follows, from reaching the face. The top coal is not taken down in the roads, nor from over the packs formed at the sides of the roads. See Fig. 204. In time, however, as the roof sinks, this top coal is ripped in an arched form, leaving a good road which requires little timbering.

There is nothing special at this colliery in the manner of timbering the main roads. Props 8 inches in diameter are used, having lids 6 inches by 5, and 2 feet 6 inches long. In some of the main roads 7-inch collars are notched into the coal on one side and supported by a short 3-foot prop resting on the coal at the other. The roads are dusty and are watered as they require it. The roof generally is very good and safe to work under, requiring little timber.

At the Cannock and Rugeley Colliery, Hednesford, South Staffordshire, the Deep Coal Seam is worked on the Longwall system. The colliery has been in

operation since 1865, and in 1881 was working both the Shallow and Deep seams, the former being 22 yards above the latter. The Deep Seam is the lowest of the series in this district, and is only separated from the Silurian measures below by a distance of 46 yards. A peculiarity of the South Staffordshire coal-field is the fact that the Coal Measures repose on the Silurian Rocks, the Old Red Sandstone, the Carboniferous Slates, the Mountain Limestone and the Millstone Grit being absent. Another peculiarity which may here be mentioned is the existence of the "Ten-Yard," or Thick Coal Seam, which is 30 feet thick.

The Cannock and Rugeley Colliery consists of the Cannock Wood Pits and the Pool Pits, the two concerns being separated by a distance of about 1½ miles. At the Pool Pits are two shafts, each 15 feet in diameter and having 70 yards of metal tubbing in it, preventing feeders of water equal to 3,000 gallons per minute finding their way into the shafts. The depth here to the Shallow and Deep seams is 326 yards and 348 yards respectively. Coals are wound in one shaft, 4 tubs, each holding 13 cwts., being placed in the cage each time of winding. The engines used for winding are a pair of horizontal high-pressure cylinders, 32 inches in diameter. As much as 1,051 tons of coal have been landed during a day of

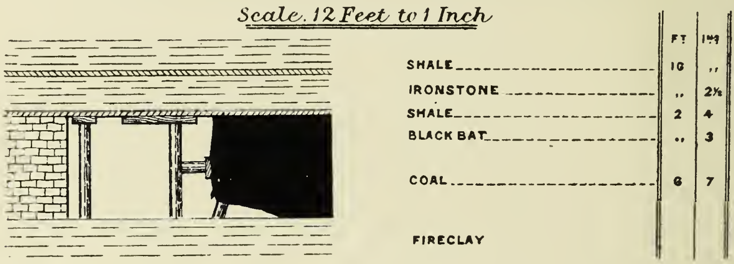


Fig. 205.—Cannock Wood Collieries, Hednesford, South Staffordshire. Section of Deep Seam, and Mode of Propping and Spragging in a working face.

8 hours, but about 900 tons is the average daily output. A 40-foot Guibal fan, 12 feet wide, running 33 revolutions per minute, produces a current of 150,000 cubic feet per minute, with 1·5 inch water-gauge, at the other, or upcast shaft.

The Cannock Wood pits comprise 3 shafts, 2 of which, 12 feet in diameter, are downcasts, the other, 16 feet in diameter, the upcast. The 3 shafts, after passing through the Shallow Seam at a depth of 178 yards, reach the Deep Seam 200 yards from the surface. The two downcasts are used to wind coal, 800 tons being landed in a day of 8 hours. Two tubs, each holding 13 cwts., are placed in the cage to be wound at one time. All coal is hand-picked, for which purpose the trams are run alongside the waggons, where the coal is sorted into 7 different qualities. Some 50 men on the pit-head sort and place 800 tons daily into the waggons. The sorting is let by contract, the price paid being $3\frac{7}{8}d.$ per ton. A Guibal fan 40 feet in diameter and 12 feet wide produces the ventilation. The fan has 2 engines, each having a 36-inch cylinder with a 36-inch stroke, and working the fan alternately for a month at a time. The fan runs 36 revolutions per minute, exhausting 180,000 cubic feet of air per minute, with a 1·5-inch water gauge. The colliers use the Williamson Safety Lamp. A borehole 30 feet in the coal of the Deep Seam showed a pressure of gas of 35 lbs. to the square inch.

The Cannock Wood pits are situated on an anticlinal axis, the coal dipping on either side of the shafts at an inclination of from 1 in 24 to 1 in 18. The Shallow and the Deep Seams are both worked by the Longwall system. The practice is to keep the workings of the lower seam 300 yards in advance of those in the upper. This plan is found to work better than either advancing them together or keeping the upper seam workings in front of the lower.

Fig. 205 shows a section of the Deep Coal Seam at Cannock Wood, and the mode of timbering at the face there. The coal is 6 feet 7 inches thick. Immediately over the coal are 3 inches of black bat, then 18 feet 6 inches of dark shale with thin ironstone in it, above the shale being 21 feet of white rock. Under the coal is fireclay.

Fig. 206 shows the method of working adopted. The gate-roads are from 30 to 35 yards apart, cross-roads cutting them off every 100 yards.

Scale. 3 Chains to 1 Inch.

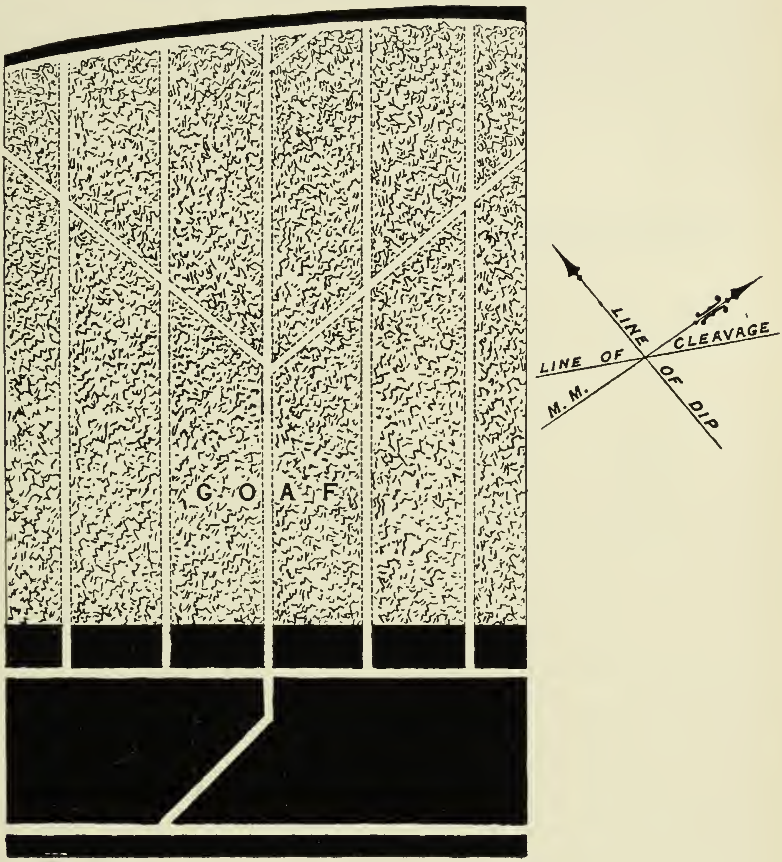


Fig. 206.—Plan showing Longwall Method of Working the Deep Coal Seam at the Cannock Wood Collieries, Hednesford.

Fig. 207 is an enlarged plan showing two gate-roads, with the manner of building the packs, and setting the timber. On each side of the roads the packs are built 8 yards wide. Next these packs are 5 yards of vacant waste, then built parallel to the roads is a central pack 6 yards wide. The road is carried 11 feet wide, having a plate at the road-head, and the rails laid along the face.

Besides the Special Rules in force in the district, regulations are issued by the manager, stating distinctly the distance props are to be set apart, as follows:—

"The distance for props to be apart on the face must not exceed 3 feet, and each prop must have a suitable lid on it. The distance between the props for a tram-

road in between must not exceed 5 feet, and a prop must be set within 4 feet 6 inches of the buttock of coal.

"The sprags under the coal must not exceed 5 feet apart, and they must be well set.

"The stall-men or contractors to see that the timber is set as above, and to see that the workmen employed by them do not work in danger.

"The stall-men or contractors to examine the way end, and all parts of the stall, and if there is any danger the men must not be allowed to work.

"The chain and bar must be used in drawing timber. Workmen found endangering their lives by neglecting to use the chain and bar, or by not setting timber to secure the roofs and sides whilst drawing timber, will be sent out of the mine at once and summoned before the magistrates.

"The competent men must see that the timber is set, as above, and examine the coal, roof, gob road and wastes of each stall, and if they find any danger, to

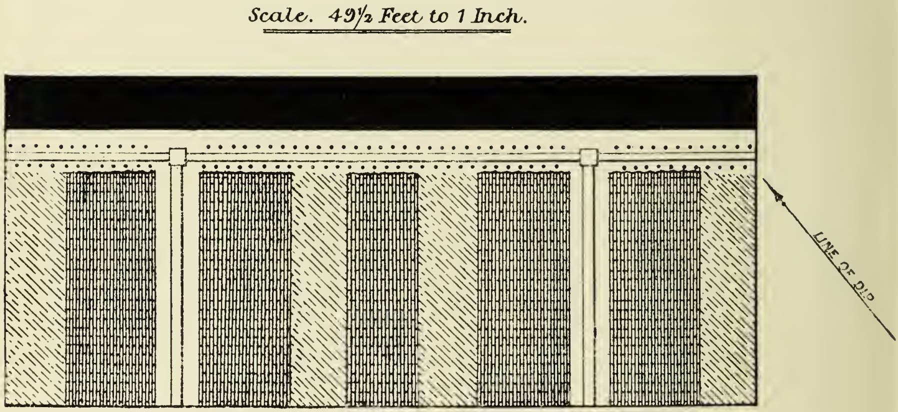


Fig. 207.—Cannock Wood Collieries, South Staffordshire. Plan showing Longwall Face in the Deep Coal Seam, and the Stalls, Packs, and Props connected with it.

stop the stall, and report the same at once to the underground manager. The underground manager to go and examine the stall, and if he finds it in a dangerous state for want of the timber not being properly set, the stall must be stopped until the danger is removed, and the stall-men to be fined not less than the sum of two shillings and six pence for each offence."

These regulations apply to the Deep Coal, and a corresponding set are framed for the Shallow Seam, in which the props at the face must not be more than 4 feet apart and not more than 5 feet between the first prop and the building.

The coal in the Deep Seam is holed under, 5 feet 6 inches in, and is supported by sprags placed 4 feet 6 inches apart. The sprags are 2 feet long and 8 inches in diameter. 2 feet back from the face, a row of 8-inch props, having broken props for lids, are set 3 feet apart parallel to the face. See Fig. 205. From the centre of each prop on the side towards the coal, is placed a short 8-inch sprag, at the other end of which is a lid bearing on the face of the coal. 5 feet back from this, another row of props with lids is set, the props being 3 feet apart, and parallel to the row in front. Close behind the last-named rows are the packs. The rails are laid along the face between the two rows of props as shown in Fig. 207. This method of getting the coal gives a large percentage of small coal, and an experiment is being made in another way. This is called "banicking."

Instead of holing in the bottom of the coal, or in the coal at all, the men hole 3 feet in the shale reposing on the coal and break the coal off with crowbars. In this way it parts at the planes of cleavage and gets into a series of steps. This method works more satisfactorily than the other, yielding 80 per cent. of large coal. In carrying out the system sprags are put in between the roof and the coal.

In each stall two stall-men or small contractors, employ two holers, and two fillers. They place the coals into the tubs, receiving 1*s.* 4¼*d.* per ton on coal for doing so. The holers receive 2*s.* 3*d.* a fathom for holing 3 feet under the coal, and for putting in the sprags every 6 feet as they go. Each of these men can hole 2 fathoms in a day of 8 hours. The wages of the fillers or loaders vary from 2*s.* 9*d.* to 3*s.* 9*d.* per day. The stall-men set up, and draw the timber out; in the latter operation, they use the "bar and chain." The roof is bad and falls when the props are withdrawn from under it. Part of what falls is used to build the packs, the rest being obtained from the ripping in the roads. The stall-men rip the roads and build the packs. The roads are 11 feet wide and are ripped 3 feet, powder being used in the process. The stall-men receive 2*s.* 10*d.* for ripping the road, which is generally, but not always, done at night.

When the holers have finished the holing on one side of the road, they remove to the other, the coal on the side they have left being shot down without interrupting their labour.

The powder is used in cartridges; the drills are all made to a suitable gauge, so that the cartridges may fit accurately the holes made by the drills. The shot-firing is carried out by a competent person, appointed by the proprietor. He superintends 8 stalls, and before commencing to drill a hole, the men consult him. The roads are timbered as required. The sets of timber in the horse-road are placed 3 feet apart. The props are 6½ inches at the thin end and 7 inches at the thick end, the thin end being placed uppermost. The collars are 7 feet long and are 8 inches square. The props are 7 feet high and are placed 4 inches nearer to each other at the top than at the bottom. In the engine planes the collars are 9 feet long. As shown in Fig. 206, the cross-roads are not carried at right angles to the stall-roads but on a slope. Chocks are placed at the corners of the buildings, 9 feet long, 2 feet wide at one end, and 5 feet 6 inches at the other, old timber being utilised in building them.

Timber costs from 3*d.* to 4*d.* per ton, the price paid at the Colliery being 32*s.* 9*d.* per 100 lineal feet for props not less than 6½ inches at the thin end. The roads are dry and dusty and are watered at irregular periods.

At the Pemberton Colliery, near Wigan, in Lancashire, the Orrell Five-feet Seam is worked by Longwall. The colliery has been working since about 1870, and consists of 4 pits, which are separated by a short distance. They are the King pit, an upcast, the Queen pit, a downcast, a shallow pit which is also a downcast, and the pumping pit. Of these, only the King and Queen pits are used in which to wind coal. The winding engines are placed between the two pits, the two engines being in one house. They are similar engines, each having a pair of 36-inch cylinders with Cornish valves. The Queen pit winding engine has a scroll drum, the diameter of which commences at 19 feet 8 inches and increases to 30 feet 10 inches. Its weight is about 48 tons. The cages have 3 decks and receive two tubs in each. 6 tubs, each holding 8 cwts., are thus raised at each winding. The drum of the King pit engine on the Wigan Four-feet rope side is 15 feet 2 inches in diameter, and that on the Cannel side is a scroll from 15 feet 2 inches to 19 feet 4 inches.

The method of removing the stones from the coal is worthy of remark. A band of flat hemp ropes is fastened together by iron bands and placed at the foot of each screen. It is 14 feet long and is carried round pulleys at either end. A

shaft by the side of this band is kept constantly revolving, and by means of a clutch the band may be thrown in or out of gear with the revolving shaft. The band is endless, and when thrown into gear moves at the rate of about 35 feet per minute. When about to discharge the coal from a tram over the screen the wheel carrying the band is thrown into gear. On the end of the screen are doors, worked by a lever, which allows the coal to fall thinly on the band as it moves. When all the coals are on it, the band is stopped by being thrown out of gear, and two women, one at each side, pick out the stones very readily. After the coal is well cleaned of impurities, the band is thrown into gear again, and the coals placed into the waggon. From 100 to 120 tons are thus daily passed over each screen, but this quantity could be greatly increased if necessary. The small coal passes through the screen bars and is led into a pit below. From here it is taken by means of a screw working in a trough, and is lifted by an endless pitch chain fitted with iron buckets, like a dredger or elevator, the coal being dropped on a screen and the duff taken out.

A Guibal fan, 46 feet in diameter and 14 feet 10 inches wide, is placed at the top of the upcast shaft. The fan is run 36 revolutions per minute, and gives

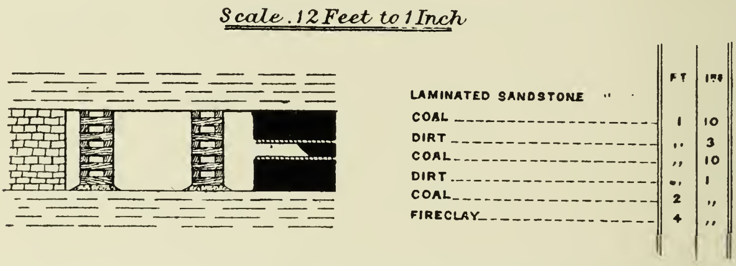


Fig. 208.—Pemberton Colliery, near Wigan, Lancashire. Method of Timbering a Working Place on the Orrell Five Feet Seam.

275,000 cubic feet of air with the water-gauge reading 2·5 inches. A direct-acting pumping engine is used to raise the water from a depth of 190 yards. Two sets of pumps are used, a lifting set in the bottom, having a 20-inch brass bucket, lifting the water 70 yards, and the one above a forcing set with a 20-inch ram raising the water the remaining 120 yards. The pumping-engine works 10 strokes a minute.

The Queen pit cuts the Orrell Five-feet coal seam at a depth of 566 yards, and the Arley Seam at a depth of 626 yards. The Arley Seam corresponds with the Silkstone Seam in Yorkshire. The coals worked in the Orrell Five-feet Seam are not put into the Queen pit cages at the 566-yard level, but at the bottom in the Arley Mine. They are transferred from the one seam to the other by means of a "blind pit," or "drop staple."

One of Fowler's clip-pulleys is placed over the blind pit at the Orrell Five-feet Seam. A wire rope attached to one cage at the bottom of the blind pit in the Arley Seam passes up the pit, round the pulley, and is attached to the other cage at the Orrell Five-feet Seam. A full tub is placed in this cage and an empty one in the other, and on lifting the brake from the pulley, the weight of the full tram causes that cage to descend and the other to be raised. The speed is regulated by the brake.

By this arrangement there is only one loading-stage in the Queen pit, all the coals being brought to the pit bottom and caged there.

The Orrell Five-feet Seam is tender in its nature, and yields a household coal. When passed over an inch screen it gives 61·3 per cent. of large coal.

Fig. 208 shows a section of the seam and the method of timbering at the face.

The coal is 5 feet thick. Over it, as a roof, is a "lea stone," or laminated sandstone, with ironstone balls, and in the roads 2 feet of this is ripped down. The coal rests on "sagger," or fireclay. Holing the coal is not regularly carried on, but the 10 inches of coal in the middle of the seam is used for the purpose when holing is done. The bottom coal is then lifted up, and the top coal supported on sprags placed under it by the collier. Afterwards, on knocking away the sprags, the top piece of coal falls. The collier sets props as well as sprags when they are required. The props used are from 3 to 4 inches in diameter.

The seam dips at an inclination of 1 in 12, and was formerly wrought by the Pillar and Stall method, the pillars left being from 20 to 30 yards square.

This method is giving way to the Longwall, as shown at Fig. 209, but some pillars are still being worked off. The coals are brought from the level next the

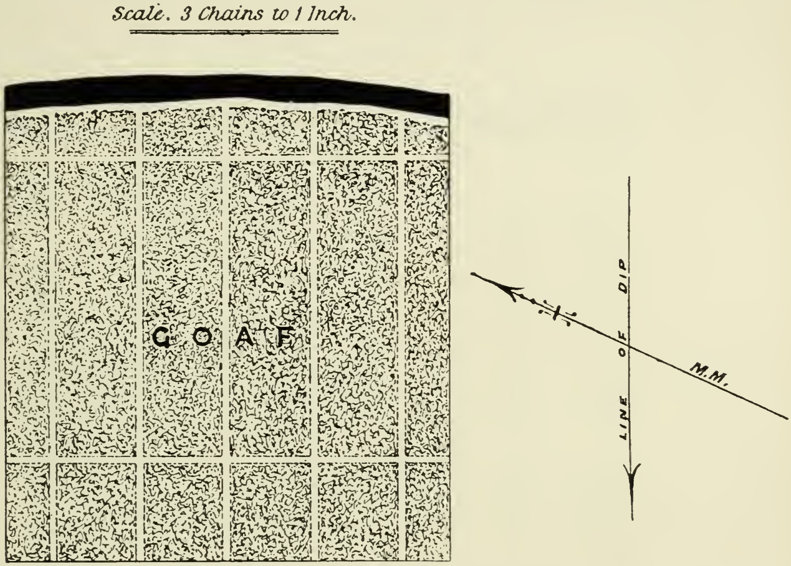


Fig. 209.—Pemberton Colliery, near Wigan, Lancashire. Plan showing Longwall Method of Working the Orrell Five-Feet Coal Seam.

face to the top of the blind pit down a "spunney," or self-acting incline. The stall-roads are driven to the full rise, as shown at Fig. 209, there being 30 yards from the centre of one road to the other. Levels running at right angles cut off the old stall-roads every 100 yards. These levels are made 8 feet wide, and have a pack-wall 4 yards wide on each side. The stall roads or brows to the face are made 7 feet wide, and have a pack-wall 3 yards wide on either side of them, as shown at Fig. 210. Four men work in a stall, two on each side of the road, and they sometimes take their own tubs of coals out to the "spunney." In other instances, two men on one side of a stall employ a younger man as their putter, and he draws the coal, and also assists to fill it.

The price paid the collier for holing and drawing is 1*s.* 3*d.* per ton. The methods of building the packs and timbering at the face are shown at Figs. 208 and 210. The latter consists in placing two rows of chocks 6 feet apart all along and parallel to the face. The distance between the two rows is 5 feet, the rails being laid between them for the tubs to be taken along.

As a third row of chocks is set, the rear row is drawn and shifted forward. The drawing of the chocks is followed by the roof breaking off behind. The fireman

sets the chocks, and for the convenience of after-removal they are built on 4 or 5 inches of small coal. They consist of billets of wood 6 inches square in section, and 2 feet long, and are a convenient size to be quickly fixed. A fireman puts one up and wedges it tightly in 5 minutes. He receives a daily wage, and attends to from 20 to 30 men. The ripping is done by a contractor, and this man takes out 2 feet from either the roof or the floor of the roads, builds the packs, which are kept within 3 or 4 yards of the face, and draws the chocks and other timber. For ripping and building the packs he is paid 10*s.* per yard; for taking out the props and chocks he receives 2*s.* 6*d.* a score for large props, but nothing for the small ones, and 9*d.* for every chock. Occasionally, where the roof is tender, he puts up a chock, receiving 3*d.* for so doing, but the fireman is expected to put in all necessary chocks. The props which the collier puts in are removed when the chocks are set. Very little timbering is required in the main roads. Where neces-

Scale. 49½ feet to 1 inch.

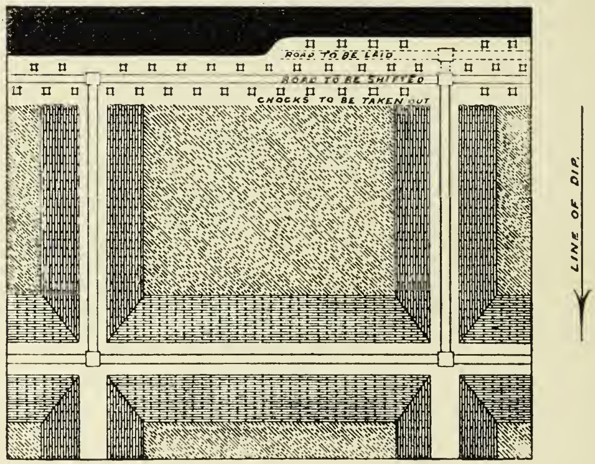


Fig. 210.—Pemberton Colliery, near Wigan, Lancashire. Plan showing Longwall Face in the Orrell Five-Feet Seam, with Packs, Chocks, and Roadway along Face.

sary, props and lids, or sets of timber, are placed. The sets are put up without any kind of notch. A special class of men put up the main-road timber during the night. They receive directions from the man in charge of the night-shift as to what repairs are necessary, &c. The roads are dusty, but are only sprinkled with water, as a more copious supply causes the floor to rise. No blasting is done in this seam, nor in any other at the Colliery, except the Pemberton Five-feet Seam.

In the Pillar and Stall workings before alluded to, pillars are left 20 yards by 30, the level roads being 3 yards and the drifts 4 yards wide. In working off the pillars, lifts, or "ratches," 5 yards wide, are worked along the whole 20 yards of the pillar. When three lifts have been thus taken off, lifts are taken out up-hill. Whilst a 5-yard lift is advancing up-hill a line of props and sets of timber are kept over the road. On the waste side of the road are 3 rows of props and lids, there being 3 feet between the rows and 3 feet between the props in a row. The props are 4 feet 6 inches long and 6 inches in diameter at the thick end. The lids are 18 inches × 5 × 2½, being made out of old props or collars. In a 20-yard lift are 100 props, 3 rows of 20, and the double

row over the road of 40. The colliers fix these props, which are afterwards withdrawn by the fireman. As soon as the colliers have finished a lift, the fireman does not wait till the men have gone out of the pit, but draws the props at once. Arrangements are being made to draw the props at night, but if it is thought that a lift will not stand till then, it will be drawn without delay. In cases where the pillars are fallen close, a strip 3 yards wide, called a "ribbing," is carried to the top of the pillar, the lifts afterwards being taken out in the ordinary way. The cost for timbering at the colliery is 1*d.* per ton in the Longwall, and about $\frac{1}{4}$*d.* per ton in the Pillar and Stall whole workings; in the Pillar and Stall broken, about the same as in the Longwall. Pit timber at the colliery costs 25*s.* per 100 lineal feet or 37*s.* per ton, and the billets of wood for the chocks cost 7*d.* each.

At the Clifton Hall Colliery, near Manchester, the method of working consists in first driving levels to the boundary, marking out blocks of coal into pillars, and working back towards the shaft.

The Colliery has been working since about 1854, the Doe, Five Quarters and Trencherbone Seams being now worked. An upcast and a downcast shaft are

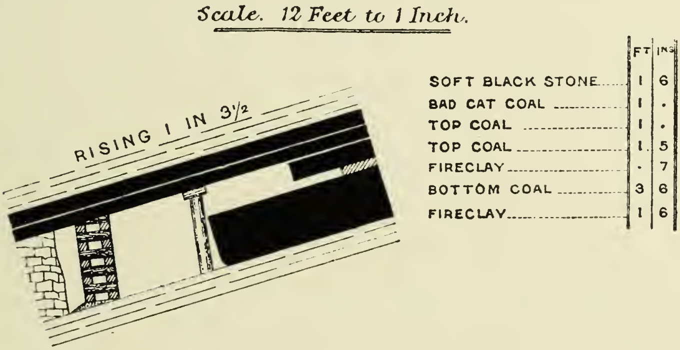


Fig. 211.—Clifton Hall Colliery, near Manchester. Section of Doe Coal Seam, and Timbering in it.

both sunk to the Trencherbone Seam. The latter solely is used for winding. The Trencherbone is the lowest of the three seams worked, being 540 yards from the surface in the downcast pit. All coal is caged at the Trencherbone Seam level. A cross-measure drift is driven water-level from the Trencherbone Seam to the Five Quarters and the Doe Seams, and the coals are brought along it. Three-decked cages are used, and the engines are fitted with spiral drums. To overcome the difficulty of changing tubs at the top and bottom of the shaft simultaneously, a balanced scaffold is placed at the bottom. The onsetter there first changes the lowest tier of tubs; he then lowers the scaffold by means of a brake and changes the other tiers. 600 tons of coal are thus daily raised.

A furnace, assisted by the steam from an underground hauling engine, and also from the furnace of the boilers supplying steam to the engine, causes the ventilation. The quantity of air passing up the upcast shaft is 100,000 cubic feet per minute.

Fig. 211 is a section of the Doe Coal Seam. The seam, including the 18 inches of soft black stone and the 7 inches of dirt, is 9 feet thick, but of this the top 3 feet 6 inches is left as a roof. This 3 feet 6 inches includes the 12 inches of top coal, 12 inches of bad cat coal, and 18 inches of soft black stone. Above this are 3 inches of ironstone, 3 feet 6 inches of hard, brittle (short) shale,

and above this white metal. Under the coal are 18 inches of warren earth or fireclay, and below this is a hard grey metal. The 7 inches of "Daugh" or fireclay is used to hole in, and the holing is carried a yard in, after which the 1 foot 5 inches of top coal is taken down. The holing is continued another yard, and the top coal over it taken down. This is continued until 9 feet of bottom coal is bared, which is then got by blasting.

The seams dip at an inclination of 1 in $3\frac{1}{2}$.

The method of working the Doe Coal Seam will be understood by reference to Fig. 212. From the extremity of the cross-measure drift between the Trencher-

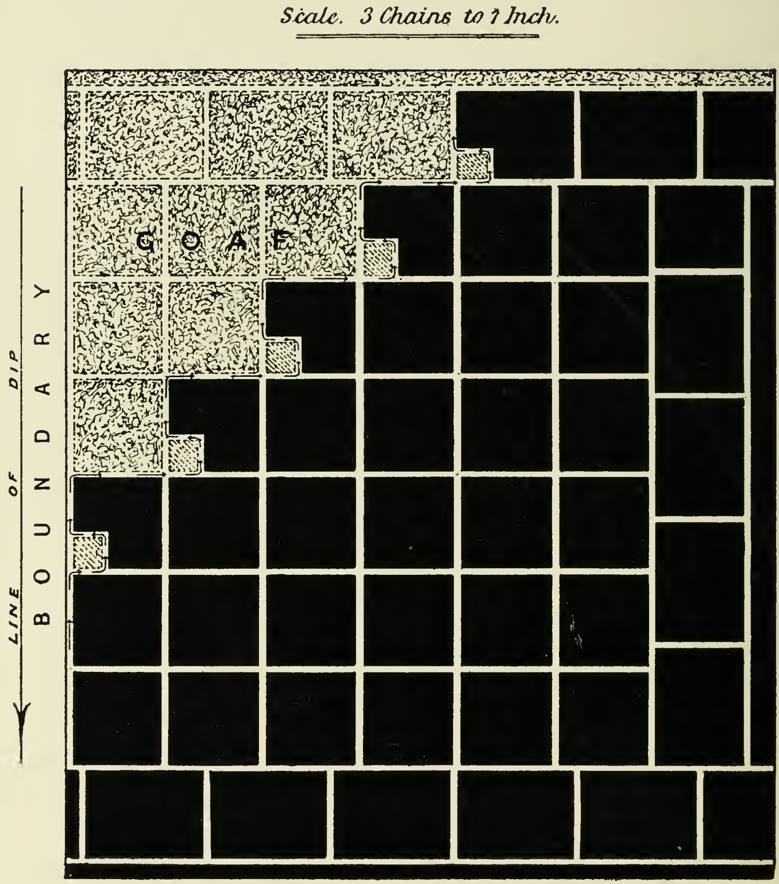


Fig. 212.—Clifton Hall Colliery, near Manchester. Method of Working the Doe Seam.

bone and Doe Coal Seams a pair of levels separated by 30 yards of coal are driven to the boundary. Openings or cut-throughs connect the levels every 40 yards. At a point 200 yards to the rise another pair of levels is driven parallel to the first pair, the coal between the two pairs being at first left solid. On the lower pair of levels reaching the boundary a pair of places, separated by 30 yards of coal, is driven out of them to the full rise from a point 200 yards back from the boundary, and these places are continued until they hole into the upper levels. Levels and throughers, all 7 feet wide, are then driven so as to divide or split up

the 200-yard square block into pillars of 30 yards square. The pillars are then worked off by taking lifts 12 yards wide across them, the coals being brought down to the levels. During the time of working these pillars the next 200-yard block outside is being split up into the 30-yard pillars, so that at no time is there more than one range of pillars being worked.

In the levels being driven to the boundary the men get 6*s*. for every $3\frac{1}{2}$ tons of coal left from riddling through a $\frac{3}{4}$-inch riddle. The levels are 7 feet wide, and the throughers from 5 to 6 feet. The air is carried to the face of the levels by brattice from the last througher. It is so placed as to form an intake of 5 feet wide on the dip side, and a return of 2 feet on the rise side of the road. The coal left on makes a very good roof, and no timber is required at the face, but further back where this top coal is taken down and the fireclay up, a good deal of timber is required, as the road is then secured with sets of timber. There is no specified distance between the sets, but they are put in where required by the men specially appointed for the purpose. Usually the distance apart is 3 feet. The props and collars used are 8 inches in diameter, the tops of the props being rounded to receive the unnotched collars. Where the weight on the collar is excessive it splits the prop down the centre like a wedge. Rafters are placed reaching from collar to collar in a line with the road, and laggings in between the rafters. Parallel to the strike are cleavages called "shuttles" in the coal. Frequently these "shuttles" set free large blocks of coal, which fall out into the roads, and thus constitute a source of danger.

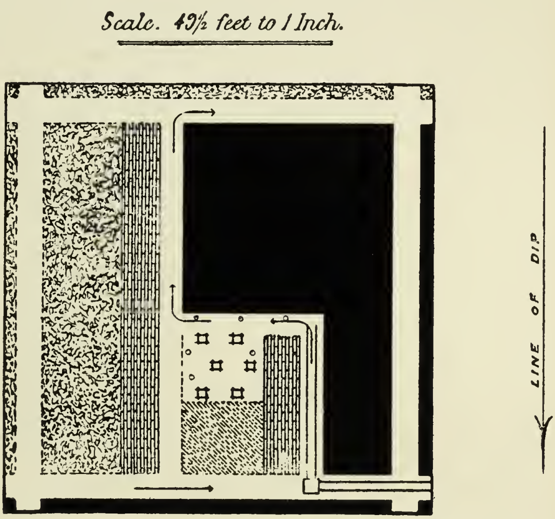


Fig. 213.—Clifton Hall Colliery, near Manchester. Plan of Lift on the Doe Coal Seam.

In the pillar workings all the seam is worked without leaving the top coal on. Fig. 213 is an enlarged plan of a pillar showing the method of taking off the lifts. Here, one 12-yard lift has been taken off across the pillar, and another is proceeding. A 6-foot wide road is carried up the side of the coal, and on the waste side of the road a 9-foot pack is built of the cat coal. Two chocks are built 6 feet back from the face and parallel to it, the chocks being 5 feet apart. Parallel to these 2 chocks and 5 feet behind them are built other two, shown at Fig. 213, whilst the 2 forming a third line of chocks are about to be removed.

The chocks are built of billets of wood, 6 inches square in section, and 2 feet long, upon 4 inches of small coal. When, owing to the great inclination of the seams, the billets do not close nicely against the roof, slips of wood are put in between the last billets and the roof to make the required close. Between the chocks and the face a row of props is set, and other props are put up as required between the different chocks. The props are of larch, 3 inches thick and 5 feet 6 inches long. The lids placed over them are 18 inches by 5 by $2\frac{1}{2}$. When the rear row of chocks is withdrawn the top coal falls in the waste, and is taken out. Three men and a lad work in the place. They hew

the coals, fill and let them down the "jig brow," build the packs, and set and draw all the timber required. They are paid 6*s.* 3*d.* for getting 10 waggons, or $3\frac{1}{2}$ tons of coal, and 4*s.* a yard for building the packs. The coal is riddled through a $\frac{3}{4}$-inch riddle, and for $3\frac{1}{2}$ tons of small coal they receive 2*s.* 6*d.* Twenty per cent. of the total quantity got is small. The 3 men and lad send out about 10 tons a day. The fireman superintends these men, and sees that the necessary props and chocks are put up.

The roof in the roads is not good; here the top coal is left on, but is taken down in the waste. Timber costs $2\frac{1}{2}d.$ a ton in this seam.

Fig. 214 shows a section of the Five-Quarters Seam, which is 24 yards below the Doe Seam. The coal is 3 feet 4 inches thick with the fireclay partings included. Of this only the 1 foot 10 inches, which is of excellent quality, is sent out. Over the coal is hard sandstone reaching up to the Doe Coal. The

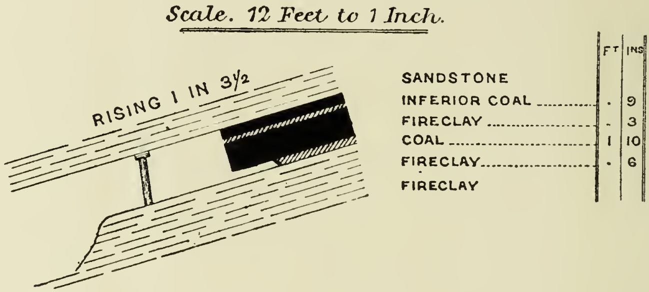


Fig. 214.—Clifton Hall Colliery, near Manchester. Section of Five Quarters Coal Seam.

6 inches of "daugh" or fireclay is used to hole in. Under the coal is "warren earth" or fireclay. To make height in the roads, water is put on this to render it soft, and it is afterwards easily taken up.

The method of working pursued on this seam differs slightly from that last described on the Doe Coal. Here, as shown in Fig. 215, instead of driving a pair of 7-foot wide levels separated by 30 yards of coal, a face or breasting of coal 13 yards wide is driven, and a single level formed in it. This road is not carried in the middle of the breasting, but to one side, in a manner similar to that on the Ram's Mine at Pendlebury Colliery, shown at Fig. 221, and fully described later on. A building 6 yards wide is formed on the rise side of the road, and another 3 yards wide on the dip side. Between the pack and the ribside on the rise side is an aircourse 3 feet wide, the aircourse being carried alongside the coal as the level advances.

A similar level is driven from a point 140 yards to the rise of this (see Fig. 215), the levels being carried thus to the boundary. When this is reached a place is driven to the full rise between the lower and the upper level from a point 140 yards back from the boundary. A block of 140 yards square is thus left. Commencing at the face of the level this 140-yard square pillar is now worked by lifts 20 yards wide being carried to the rise across it between the two levels. The road is carried in the centre of the lift, and protected on each side by a facing built of the 9 inches of inferior coal. The rubbish yielded in ripping the roads and in holing the coal is sufficient to fill the whole space in the waste. An aircourse is formed along the ribside. No chocks are used, but props are set 6 feet apart along the face. The props are 3 inches thick, and $3\frac{1}{2}$ feet long, the lids over them being 2 feet × 5 inches × $2\frac{1}{2}$ inches. The props are not set at right angles to the floor of the seam, nor in a vertical position, but at an

inclination between the two, so that as they afterwards sink they assume a position more nearly at right angles to the floor. Only one lift at a time is taken out across the pillar. The collier receives 8*s*. 8*d*. for $3\frac{1}{2}$ tons of riddled coal, but he has to draw the coal to the foot of the second jig brow for this, some 200

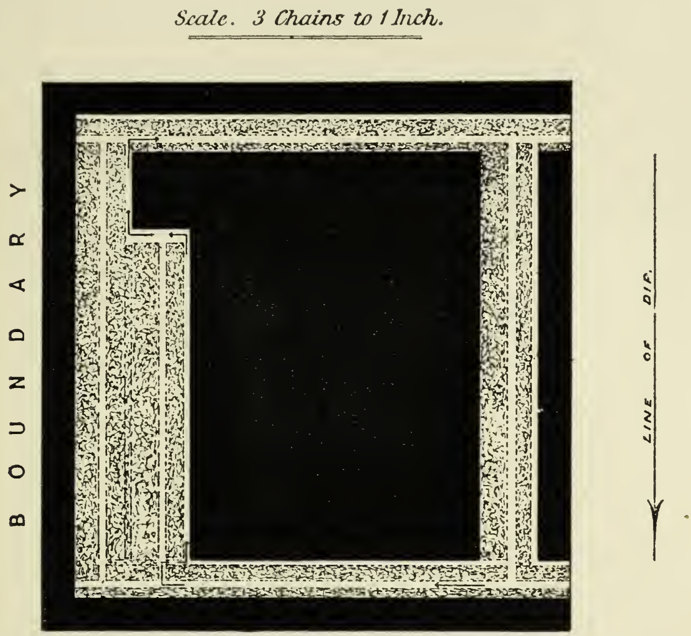


Fig. 215.—Clifton Hall Colliery, near Manchester. Plan showing Method of Working the Five-Quarters Coal Seam.

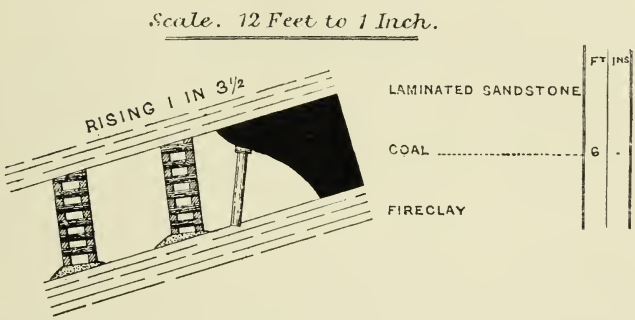


Fig. 216.—Clifton Hall Colliery, near Manchester. Section of Trencherbone Coal Seam.

yards distant. He puts in all the props, and receives 3*s*. a yard for the pack facings in the road. Four men work in a lift, and they send out about 7 tons of coal a day. From experiment it is found that this seam works badly if the Doe Coal is first worked over it. The rock roof is excellent.

The Trencherbone coal is 180 yards below the Five-Quarters. A section of it is shown at Fig. 216. There are 6 feet of coal without any partings in it. Over it are 4 feet of laminated sandstone; then a thin "chitter" coal 15 inches thick,

called the California coal ; over this, again, is a very hard red sandstone, 24 yards thick, called the Trencherbone rock. Under the coal are 18 inches of "warren," and beneath this are 4 feet of "warren," 4 yards of shale, a thin coal, and then shale.

In working the Trencherbone Seam in the Manchester district, boulders have been found in the coal, in the roof over the coal, and sometimes half embedded in both coal and roof. The Trencherbone is by no means the only seam of coal

Scale. 49½ feet to 1 Inch.

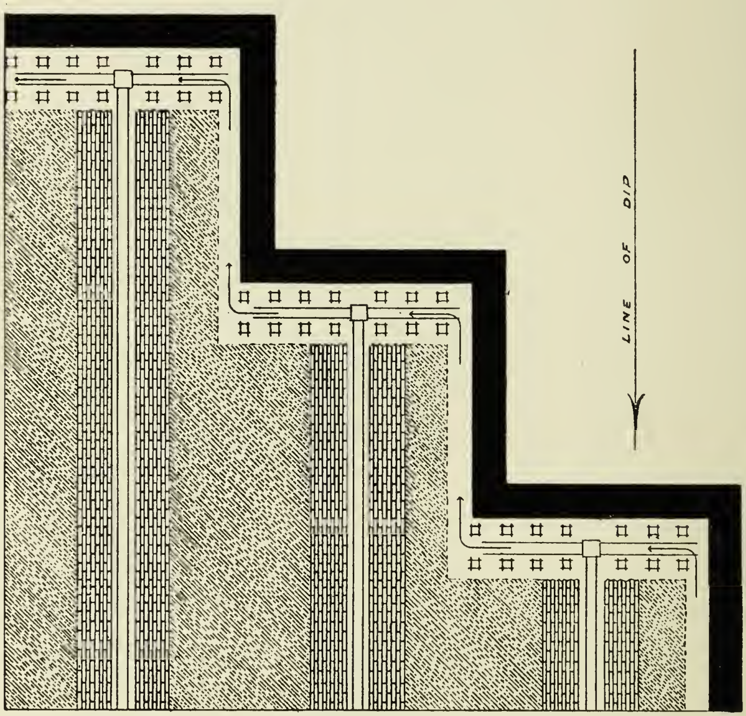


Fig. 217.—Clifton Hall Colliery, near Manchester. Plan of Three Lifts Advancing at the same time in the Trencherbone Coal Seam.

which has yielded these boulders ; they have been discovered in the Arley Mine at Burnley, in the Roger Seam of the Astley Pit, Dukinfield, in the lower coal measures (the gannister coal or Mountain Mine) at Bacup, Lancashire. The last-mentioned are 1,000 feet below the Arley. Some coal seams of the United States yield boulders, having the same character and composition, and occupying the same position in the coal seams as those in the Lancashire coalfield. As a rule, they are hard, siliceous grits or quartzites of a pale or dark grey colour. They vary much as to size and form, but all are smooth, and often polished, with corners rounded off by abrasion, giving evidence of their being water-worn before being deposited in the coal strata. These boulders are well worthy of notice, as they have caused much speculation among geologists as to how they were brought into their present position, and from whence. They are older than any

rock of the Carboniferous period (one found at Bacup being of granite), some of them are of great size, and there must have been some unknown means of transport, to distribute them over areas so widely separated as England and America. The whole of this interesting problem is as yet unsolved.

The method of working the Trencherbone Seam at the Clifton Hall Colliery is similar to that of the Five-Quarters last described. The levels are driven in precisely the same way, but the pillars are only 100 yards square, and instead of only one lift being taken off the pillar at a time, at least two, and sometimes three, are taken up-hill at the same time, as well as one or two going down-hill. The collier uses a windlass to draw the coals up from those places going down-hill. Fig. 217 shows three lifts proceeding at the same time to the rise. They are driven 20 yards wide, the face of each being kept from 20 to 28 yards in advance of the one behind it. The road is formed in the centre of each lift, and on either side of the road a pack 3 yards wide is built. A double row of chocks is kept next the face and parallel to it. The rails are laid in between the chocks, which are 5 feet apart as shown at Fig. 217. As the face advances sufficiently, another row of chocks is put in and the rear one withdrawn. Before proceeding to take down the rear row, props are set around each chock. The rubbish on which the chock was built is cleared away, and the chock knocked out at the bottom. The props giving security round the chock are then taken out, and the roof falls. The sprags shown in Fig. 216 are placed to prevent the coal riding over. They are 5 feet 6 inches long, and the lids over them are wedge-shaped.

The roads are dry and dusty. Generally the roof is good, and the main roads do not require much timbering; in places where the roof is bad props and sets of timber support it, cross-pieces and laggings being placed over the collars. The two props of a set are not of the same thickness, the one to the dip being 5 inches in diameter, and that to the rise 4 inches. The collar is 7 inches in diameter. It is said that an advantage arising from this system of working is the fact of keeping the weight on the face and off the roads.

No blasting is done in the pillar working.

The Pendlebury Colliery adjoins the Clifton Hall, the two collieries belonging to the same company. It has been working since 1848, and at present works the Shuttle, Crumbouke, and Ram's Mines, by means of an upcast and a downcast shaft. The latter is 400 yards deep to the Shuttle and Crumbouke coal. At the pit bottom, a direct-acting pump raises the water in one lift to the surface.

The upcast, Furnace, or No. 2 Pit, is used to wind coal from the Ram's Mine. The workmen also ride up and down it, and as it is very hot, to guard against serious consequences through the cage being stopped by accident in the shaft, a signal is provided by which communication is made with the pit bottom from the cage. The onsetter on receiving such signal can open the separation doors and let the fresh air into the shaft.

A section of the Ram's Mine is shown at Fig. 218. The coal is 5 feet thick, besides the 4 inches of inferior coal which is left on in the working, but taken down in the roads. Over this inferior coal are 7 yards of blue metal, 3 feet of which are taken down to make height in the roads. Under the coal is blue metal. The coal is first holed in the middle at the parting, and the top coal then taken down, and kept 3 feet in advance of the bottom coal, which is blasted. A competent person is employed to fire the shots. In some places, the seam is holed in the 4 inches of daugh under the coal, but this does not run continuously through the seam. Where holed under the seam, sprags 18 inches long and 6 inches high are put in with wedges on the top.

The Ram's Seam is 200 yards above the Doe Seam, being worked at Pendlebury in the same way as the Trencherbone Seam is worked at Clifton Hall. An underground hauling engine, supplied with steam from boilers placed at the

bottom of the upcast, hauls coal up a road driven 500 yards to the dip. The whole of this road is secured with brick arching. Levels are driven out of this dip road. At the far end of the dip, and for a short distance along the lowest level leading out of it, are some double-headed rails used as props, see Figs. 219 and 220. Two uprights 6 feet long support a curved crown 10 feet long

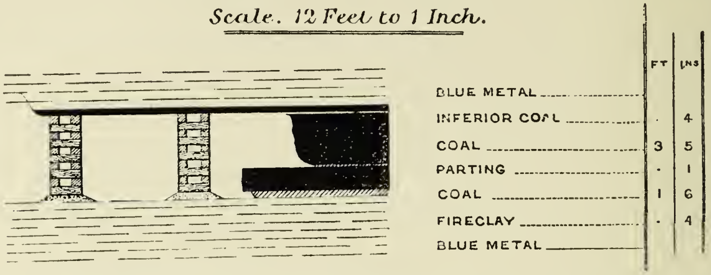


Fig. 218.—Pendlebury Colliery, near Manchester. Section of Ram's Mine Coal Seam and Timbering in it.

The uprights are set on sills, 12 ins. × 5 × 7. The crowns are curved slightly, having a versed sine of 6 inches. To keep them securely in place, short props 6 inches long and 6 inches thick are wedged in between the end of the rail and the side as shown in Fig. 219. These sets of rails are fixed every 4 feet along

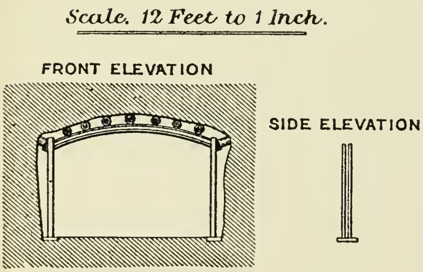


Fig. 219. Fig. 220.

Pendlebury Colliery, near Manchester. Method of Securing Roof by Double Headed Rails.

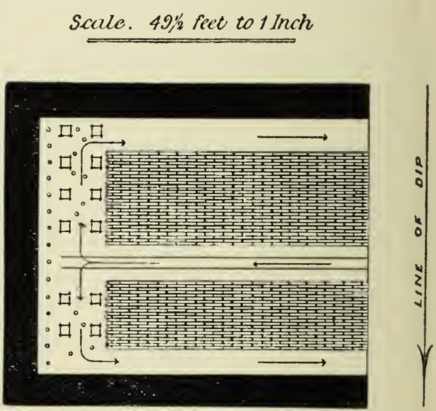


Fig. 221.—Pendlebury Colliery, near Manchester. Plan showing the Face of Level in the Ram's Mine.

the level for some distance, and rafters placed over the crowns. Little or no timber is used in the rest of the level. Owing to a fresh arrangement the boundary line was altered after this level had been driven and the coal worked back. It became necessary, through the boundary extension, to drive the level on again. At the point it had been standing, the roof was tender and required props and sets of timber to secure it at that point, but not elsewhere. The level is driven 20 yards wide, as shown in Fig. 221. On each side of the road, which is 9 feet wide, packs are built. The pack on the rise side of the road is 8 yards wide, and above it is an aircourse 9 feet wide extending from the pack to the coal. The pack on the low side of the road is 6 yards wide, and beyond the pack on the low side is an aircourse 6 feet wide. The face is protected by 2 rows of chocks, a row on the rise side consisting of 4 chocks and on the low side 2.

The rows are 6 feet apart, and as the face advances sufficiently the rear row is drawn out and set up in front. When about to draw a chock, props are set up round it, and after the withdrawal of the chock, the props are taken out. Besides the double row of chocks, a row of props is set up next the coal, and others again between the chocks, as required. These props are 4 inches thick. Altogether there would be 12 chocks and about 30 props protecting the face, but the number of props varies. Occasionally chocks are set in the road between the rails and the packs, at intervals of 6 feet.

The stall-man sets the props and chocks, and they are taken out by the person who fires the shots. The stall-man receives 7*s.* 7*d.* for $3\frac{1}{2}$ tons of coal, and 4*s.* 7*d.* for $3\frac{1}{2}$ tons of small coal. The advantage claimed for this method of driving the levels is that it is safer in a fiery mine, as the face advances more slowly and gives the gas time to drain. The roof is fairly good, and the timber costs 2*d.* a ton.

At the Sovereign Pit, West Leigh, near Manchester, the West Leigh Seam is worked on the Longwall principle. It corresponds with the Wigan 9-feet, and the Trencherbone at Clifton Hall. The colliery consists of an upcast and a downcast shaft, each 376 yards deep. A pair of 36-inch cylinder high-pressure engines, fitted with Cornish valves and having a $6\frac{1}{2}$-foot stroke, winds coals in the downcast pit. Flat wire ropes are used, the drums being 15 feet in diameter. At the upcast shaft is a Guibal fan, 40 feet in diameter and 15 feet broad, the pit being used solely for ventilation. A horizontal engine, having a 30-inch cylinder and 3-foot stroke, with Cornish valves, drives the fan. A duplicate engine also drives the fan, the two working 8 weeks alternately. The fan runs 35 revolutions a minute, at which speed it exhausts 200,000 cubic feet of air per minute with 1·6 inch water-gauge.

The West Leigh Five-feet Seam is very fiery, and, like the Barnsley Seam in Yorkshire, subject to sudden outbursts of fire-damp from the floor. The gas is emitted from a thin seam of coal 14 yards below. To lessen the danger arising from an overwhelming discharge of this gas, boreholes are put down from the workings, which allow the gas to pass up in smaller quantities, which may be regulated and controlled.

In 1881 there were two such boreholes, each having a tube with two branches on top of the borehole. A pressure-gauge on one of them indicated a pressure from the gas of 15 lbs. per square inch.

On removing the pressure-gauge and opening the cock the gas rushed with great velocity from the tube, accompanied by a roaring noise like that of steam issuing from a boiler under great pressure. After allowing the gas to escape for a few seconds, a test of the pressure-gauge showed a diminution of the pressure equal to 5 lbs. per square inch. On closing the cock, the pressure gradually increased again until it had attained its original pressure. During the hours the workmen are in the pit, the cocks on these boreholes are shut and the gas not allowed to escape, but when the men are all out, the fireman turns the cocks and the gas issues from them for 10 hours till he makes his morning examination, at which time he closes them for the day. There being no work on Sunday, the gas is allowed to issue all that day, and in consequence the pressure is much lessened on the Monday morning. The gas in a borehole, once left open during a strike of the men, became completely exhausted; but on work being resumed the gas again accumulated and issued from the borehole.

Much fire-damp is emitted from the roof also, and a fall is always succeeded by large quantities being given off. The gas is much more explosive than ordinary fire-damp, and it is almost impossible to get a cap on the lamp with it. Three per cent. of it mixed with air and charged with dust is explosive. Mueseler safety lamps are used by the workmen.

The strata dip at an inclination of 1 in 6.

Fig. 222 shows a section of the seam. There are 4 feet of coal, and above it 10 inches of inferior coal. This inferior coal is left on for a roof. Over this are 19 yards of laminated tender shale. If the coal is taken from under this shale in narrow work, the shale has a tendency to break down in gutters over such excavations, and therefore makes a bad roof; but when the coal is worked on the Longwall system, it makes a very fair roof. The thill is 2 feet 3 inches of shale, under it being 4 inches of fireclay; then 2 feet of fireclay and blue metal, below being 42 feet of blue metal with bands of coal; then the thin seam of coal before alluded to and to which the boreholes are pierced.

The 2 feet 3 inches of shale and the 4 inches of fireclay are taken out along with the coal. The 4 inches of fireclay are used to hole in, and the shale is taken down to give height while the operation proceeds. Sprags 5 feet 3 inches long

Scale. 12 Feet to 1 Inch.

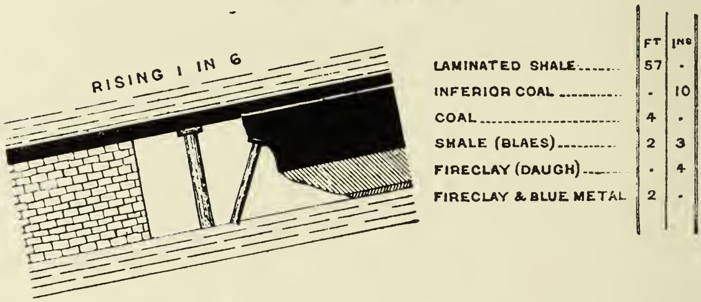


Fig. 222.—Sovereign Pit, West Leigh, near Manchester. West Leigh Five Feet Seam showing Props and Sprags used there.

and 6 inches in diameter are placed against the coal to prevent its riding over as the holing goes on, as shown in Fig. 222. The holing is carried 6 feet under the coal, after which the sprags are removed and the coal allowed to fall. The 2 feet 3 inches of shale are used to build the pack-walls at the sides of the roads, the whole space in the waste between roads being filled tightly and closely with rubbish.

The method of working is shown at Fig. 223. The levels are driven every 80 yards, and the stall-roads are from 12 to 20 yards apart. If there is too much rubbish yielded the roads are kept more than 12 yards apart, so as to allow more stowing room for the rubbish. The roads are not ripped. If a road sinks till it is too low, it is not repaired but abandoned, and a level road is driven through the gob cutting it off. This is found preferable to driving a road from the face, because the roof having settled back in the waste, a road afterwards made in it is easier maintained. The object of driving the stall-roads in the direction shown at Fig. 223, rather than at right angles to the levels, is to render the gradient easier for the tubs. One road is however always kept at right angles to the levels and used as a "jig brow." A chock is built in the acute angle of the building in the road near the face. The sprags are placed every 4 feet against the coal, the props a similar distance apart and a little back from the face between the sprags. At the road-head are two chocks placed 8 feet apart.

The roads are secured by props and sets of timber placed 3 feet apart, and chocks are placed at the corners of buildings where stall-roads are turned. Some of the sprags have an iron band $1\frac{3}{4}$ inches wide and $\frac{3}{8}$ inch thick on either end, to prevent their splitting. These last much longer than those not so protected. A blacksmith puts rings on 30 props in a day.

Two colliers work in a 20-yard stall, each having a working face of 10 yards from the road. Each employs a drawer. The collier receives 1*s.* 4*d.* per ton for large coal and 1*s.* per ton for small. For this he holes the coal, sets the sprags, gobs the rubbish, and delivers his coal at the bottom of the jig brow. Of the coal got 95 per cent. is large.

A collier sends out an average of 7 tons of coal in a shift of 9 hours. Special contractors put in the packs and chocks. They are paid 6*d.* a ton on the coal sent out for building the packs, setting and drawing the props and chocks. The roads from the pit bottom inwards are under their charge, and they work on them both by day and night. Four-fifths of the work is, however, performed dur ing es. day time. There are two pairs of contractors in the pit, one to each set of facthe

Scale. 3 Chains to 1 Inch.

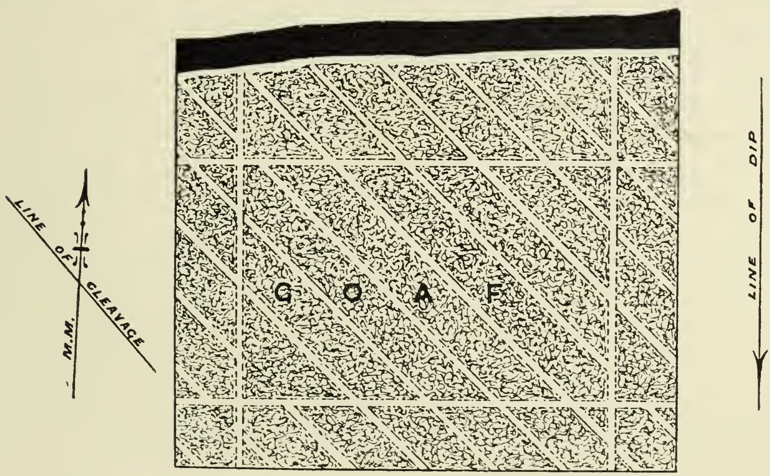


Fig. 223.—Sovereign Pit, West Leigh, near Manchester. Plan showing the Method of Working the West Leigh Five-feet Seam.

Each pair employs 18 or 19 men to look after a face 700 yards in length. There is a proportion of one of these contractor's men to 3 colliers. About 85 per cent. of the faces work on end. In the pit are 74 colliers, who send out 400 tons of coal a day. About 53 of these employ a drawer, and 21 draw their own coal. Their working day extends from 5 A.M. to 3.30 P.M. One overman directs operations in the pit, in which, besides the workmen, 7 horses are employed. The cost for timber at the face is ½*d.* per ton.

The price paid for ordinary pit timber at the colliery is 9*s.* 8*d.* per 100 lineal feet, and 1*s.* 3½*d.* per cubic foot for larch. The roads are not dusty, but somewhat dry.

At the Radstock Collieries, Somersetshire, the thin seams of the Radstock group are worked on the Longwall system. The Somerset Coal Measures consist of two productive coal series, divided by a thick mass of almost unproductive hard grey sandstone and grit called Pennant. It is from 2,000 to 2,500 feet thick and separates the upper or Radstock from the lower or Kingswood and Bristol series of coal seams.

The upper series is locally subdivided into two groups, the upper group con-

stituting the coalfield of Radstock and Camerton, and the lower the coal district of Farrington, Parkfield, and Coalpit Heath.

Similarly the lower series is subdivided into two groups, an upper one worked at Kingswood and Newbury, and a lower one worked at one time at Vobster and Twerton, and at present around Bristol.

The upper or Radstock group of the Coal Measures attains a thickness of about 1,000 feet and contains six workable seams varying from 1 foot to 2 feet 4 inches each in thickness. Those 1 foot thick are called *thin* at Radstock, and those two feet thick and upwards are called *thick*.

Between the Radstock and Farrington groups is a mass of red shale about 150 feet thick, making a very marked line of division. The Farrington group averages 750 feet thick, and contains six workable seams of coal.

The Pennant contains two or three workable seams.

In the lower series there are about twenty-six seams in its central area, decreasing to seven in the northern area. In the Nettlebridge valley, the coal measures of the lower series are from 3,000 to 3,500 feet thick, whilst in the Kingswood district they average 2,700 feet, and in the Bristol district 2,000 feet.

The total thickness of the coal measures is at least from 6,000 to 7,000 feet.

A peculiarity of this coalfield is that four-fifths of the whole of it is covered by newer formations, resting unconformably on the coal measures. These newer formations consist of New Red Sandstone, Lias and Oolite, and the coal seams worked under have their outcrops hidden by them. The New Red Sandstone, Lias and Oolite are nearly conformable to each other, and at Radstock are found almost flat.

At the base of the New Red Sandstone, there is a conglomerate, locally called "Millstone," which is believed to correspond with the Magnesian Limestone in the North of England. It consists of blue stones, which in size vary from half an inch to a foot thick, bedded in a red matrix. The stones have a rounded, water-worn appearance. This conglomerate is extremely hard and impervious to water. A pit in being sunk to the coal measures first passes through the overlying formations, and in the New Red Sandstone large quantities of water find their way into the shaft. These are pumped out until the conglomerate is reached, when the water is "tubbed back." The wedging crib is laid in the conglomerate and the metal tubbing run up through the water-bearing strata.

Whilst the newer formations are almost free from faults, the coal measures beneath present a marked contrast. Faults, varying in size from a few inches to a hundred fathoms, are found running through the district in every possible direction, the seams of coal lying in disconnected pieces between, sometimes level, at others at angles more or less inclined up to vertical, and even folded back with the floor of the seam uppermost.

An anticlinal axis at Kingswood divides the coal measures into two basins, the Northern or Gloucestershire being the smaller, and the Southern, constituting the Somersetshire, the larger basin.

The most remarkable of all the faults is the Overlap or Slide Fault of Radstock. This fault displaces the seams of coal vertically about 36 fathoms, and some of the pits sunk have proved the same seam twice, thus multiplying the coal seams in the shafts. In the manor of Radstock where the workings have been carried against this Overlap Fault and the facts carefully ascertained, the amount of folding over or overlapping of the seams varies from 120 yards on the highest of the 6 workable seams to 330 yards on the lowest.

The Radstock district yields a beautiful variety of fossil plants.

The method of working the six seams of the Radstock group is shown at Fig. 224. The bottom seam of the group lies more than 300 yards below the surface. No pillars are left either to support the shafts or the levels. Where the coal is taken out at the shafts, strong arching is thrown over to secure the road. Owing to the disturbed nature of the ground, levels are not carried from the shafts as in

most districts, but cross-measure drifts or "branches" are continually being driven to win pieces of coal lying between faults.

Fig. 224 shows the method pursued where the seams are rising 1 in $3\frac{1}{2}$, which inclination prevails over a certain area. The roads going to the full rise out of the bottom level are from 35 to 40 yards apart. One of them is made into an incline, the top or bottom being ripped for the purpose, and it is at first made 6 feet high. The other rise roads are only made "topple height" or about 4 feet. A level out of the incline on either side cuts off the old topples every 100 yards. The levels are made 6 feet high. When the face has advanced 100 yards, another

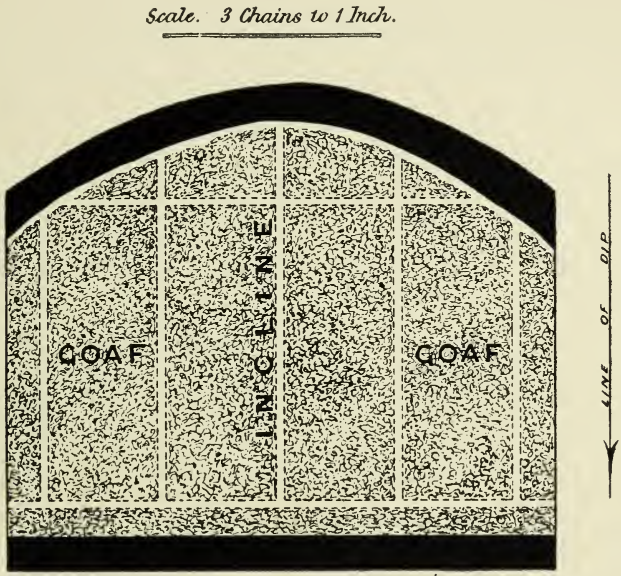


Fig. 224.—Longwall Method of Coal Working in the Upper Series of the Somersetshire Coalfield at Radstock.

incline is made above the lower one. The coal is taken out for 5 or 6 yards below the bottom level, as shown at Fig. 224.

Two colliers and a lad work together in a road, and their operations are confined to 20 yards on either side of it. Open lights are used throughout, no firedamp having ever been seen in the Radstock group of seams.

The men hole in the soft shale either above or below the coal, as may be most convenient, and use wedges afterwards to get the coal. Very little spragging under the seam is done. The coal, after it is holed under 3 feet for a considerable distance, being of a hard unyielding nature, requires wedging before it separates from the roof. The colliers set their own props, a double row being used along the face with lids or "traps" over them. There is no rule as to the distance apart of these props. They are 3 or 4 inches thick, and vary from 1 foot to 2 feet 6 inches long according to the thickness of the coal. The boy working with the two men hauls the coal out on a sledge or a board along the face to the road-head. The lad doing this work is called a "carting boy," and his sledge a "put." He brings the coal 20 yards from either side of the road, and in the case of the bottom level he is expected to haul 30 yards from the high side, and 10 yards from the low side of the road if required.

The "carting boy" fills the sledge, or, when he has large lumps, a board, and

by means of a "guss" and chain hauls out his load. The "guss" is a rope band worn round his middle, the chain is suspended from it in front, and a "crook" of iron is used for readily hitching it to the sledge or board ring. The chain is passed between his legs, and he goes on his hands and knees in a "thick" seam, but serpent-like, clutching at the props with his hands and bearing against them with his feet to help him on in the thin seams.

From the road-head larger sledges, which are piled up much higher than they can be along the stall, are taken out to the top of the incline by "twin boys," or boys running in the "twinway."

A small pulley is secured at a road-post or at one of the sleepers, and a chain passed round it, with one end attached to the back part of the loaded sledge near the road-head, and the other to the front end of the sledge at the foot of the topple. Only one tramway is laid in the topple, and that not of iron rails but wooden "crease." It is made similar in shape to the tram rails for keen-edged wheels, but in being laid is reversed, the vertical part being placed outside the horizontal. The sledges are shod with iron, and this "crease" forms a groove in which they slide, without running on wheels down steep places. When the loaded sledge is started at the top of the topple it proceeds slowly, followed by the "twin boy" till it comes into collision with the empty. The latter is then turned on its side and dragged on a yard or two whilst in this position by the full sledge in its farther descent. When it is clear of the loaded sledge the twin boy turns it over fairly into the "crease" and then leaves it to follow the load down as the empty proceeds upwards. At the foot of the topple, the sledge is "carriaged." A carriage is a skeleton frame running on wheels, made for the reception of the sledge. The twin boy pushes the carriage sufficiently away from the foot of the topple for a large board or stage to be dropped over the rails (iron) running along the level road, and called a "twinway." The carriage is then brought against the board, their upper surfaces being nearly on a level when so placed, the sledge drawn from the foot of the topple on to the board, and from there placed on the carriage. Here it is run out to the incline, where it is taken off the carriage and let down the incline accompanied by and attached to two or three others without wheels. A double line of wooden rails is used in the incline, and to prevent the lumps of coal dropping off the puts which are piled high, a chain is passed over them. At the foot of the incline the coal is transferred into tubs and taken out to the shaft by horses.

The top shot down in the roads is used to build the pack-walls on either side. These are mere facings, and the rubbish made in holing is stowed in the gob. In a thin seam, the waste will not hold all the rubbish, and some of it is loaded and sent out to the shaft. The thick seams hold their own rubbish, and in cases where it is not sufficient to closely fill the waste, it is thrown into "tumps," that is, it is built in the waste with alternate spaces and rough packs. The collier receives a rate per ton, which varies according to the thickness of the seam. He sets all his own face timber, and throws his rubbish back. He also rips the road and builds the packs there, but for doing so he receives in addition to the tonnage rate on coal a yardage price in proportion to the height he makes the road. The carting boy is not paid by the collier, but he and the twin boy both receive a tonnage price, varying in the one case in proportion to the thickness of the seam, and in the other to the distance the coal is taken. Timbermen are appointed who receive a daily wage for withdrawing the props at the face and building the tumps. A large number of the props are not recovered. When they are, they are struck out by blows from a hammer, and not by a "dog" and chain. The roads crush very much after being made, and require frequent shooting down to maintain them at their height. Sets of timber are used in the main roads. They are placed without any kind of notching, and are of various sizes according to the difficulty of keeping open any section of the road.

No cogs are used at the face or in any of the main roads.

In those areas where the seams lie flat, or at an easy inclination, instead of the puts used in topples all the roads are made 6 feet high and the horse takes the tubs to the face. If a pit at Radstock raises 150 tons of coal in a day of 8 hours, it is considered good work, but it must be remembered that rubbish is hauled as well, and the natural disadvantages to contend with are very great. The shafts are small, usually not exceeding 8 feet in diameter.

At the Kingswood Collieries, near Bristol, the seams of the lower series are worked by Longwall.* The seams are steep and have a bad roof, making them expensive to work.

Fig. 225 is a plan showing the method of working the Great Seam or Vein at Kingswood, the seam being about 4 feet 6 inches thick here. From the bottom,

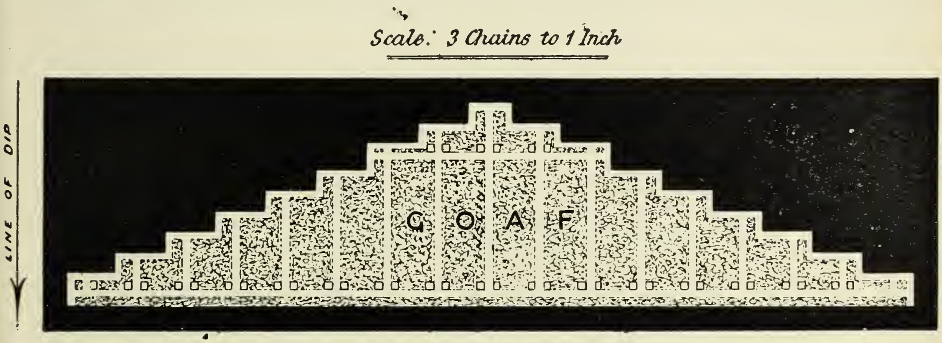


Fig. 225.—Longwall Method of Working the Great Vein of the Lower Series in the Somersetshire Coalfield at Kingswood, Bristol.

or main level, "hatchens," as they are called, are carried to the rise. At the corners of these hatchens, packs 4 feet square are built as shown in Fig. 225 on either side of the road. These points are made filling places, plates being placed so that the tubs can be pushed in round the corner clear of the rails. The top is not shot down in these hatchens, but the coal is brought down in one of three ways, determined by several conditions such as, inclination of the hatchen, scarcity of boys, &c. First, where lads are not employed, the coal is let down in shoots, and the supply of coal through it into the tubs is regulated by a hopper. Secondly, by making the hatchen a self-acting incline, a small pulley being used round which the chain passes and the pulley is shifted as the face advances. Thirdly, by lads taking "sleds" up and down. In this case a chain is secured at the top of the hatchen and lies in the middle of the road, the lads using it as a hand-rail to pull by in ascending the road, and to act as a "drag" in bringing the loaded "sled" out.

After being driven 44 yards, the hatchen intended for an incline is ripped and the rails are laid, a drum is fixed at the top, and the hatchen becomes a "Gug" or incline. A level road, one on each side from the top of this incline, cuts off the old hatchens from the lower level.

The levels are ripped right into the face, by one shift of rippers following two shifts of colliers. The face in a level road is carried 9 yards wide, 5 yards above and 4 yards below the road; the pack on the rise side is built 4 yards wide, and that on the deep side about 3 yards.

The packs built on each side of the hatchens vary from 3 to 4 yards wide. From the lower side of the main level a cross-cut is turned to the low side, and

* See Transactions, North of England Institute of Mining Engineers, vol. XXVII., pp. 96–97.

continued parallel with the main level as soon as there is room enough to give 5 yards of coal on the rise side. This cross-cut (not shown at Fig. 225) is ripped and packed precisely the same as the levels. Its chief use is as an intake for the air going inbye.

Two colliers work in one place. The air, after circulating round the face, passes into a higher district or by a cross-measure drift or branch into the overlying seam, called the Thorofare, on which, the roof being excellent, the returns are carried.

The Upper and Little Toad Veins are worked in a manner similar, differing chiefly in the length the hatchens are carried, which are 80 yards in the former, and 60 yards in the latter seam.

The roof of the Great Vein is so bad that the main roads are carried in the Little Toad Vein, and these roads are connected to the Great Vein workings by cross-measure drifts of 120 yards in length as occasion requires, the roads on the Great Vein being then abandoned and allowed to fall.

At the Allanshaw Colliery, Hamilton, Scotland, the Ell Coal Seam is worked by the Pillar and Stall or "Stoop and Room" method.

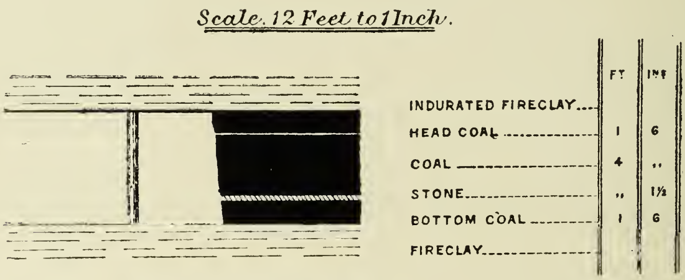


Fig. 226.—Allanshaw Colliery, Hamilton, Scotland. Section of the Ell Coal Seam.

The colliery has been working since about 1876, and consists of an upcast and a downcast shaft, each being 234 yards deep to the Ell Coal Seam. The shafts are circular in form, although the usual practice in Scotland is to sink rectangular pits, and then to divide them into two compartments, one for each cage; or if a set of pumps is to be placed in the shaft, it would have three compartments, the additional one being for the pumps. The Allanshaw pits are each 13 feet 6 inches in diameter. In 1881 the downcast solely was used for winding, although a pair of horizontal, high-pressure winding engines, with 26-inch cylinders and 5-foot stroke, had been placed at each shaft. At present (1890) each shaft is used for winding. Single decked cages, each carrying one tub or hutch which holds a ton, are used.

A Guibal fan 20 feet in diameter and 5 feet wide, exhausts the air at the upcast, and runs 40 revolutions per minute. At this speed it gives 40,000 cubic feet per minute with ·5-inch water-gauge. About 450 tons of coals are landed in a 10-hour day.

Fig. 226 shows a section of the Ell Coal Seam. There are 7 feet of coal, which parts badly from roof and thill or pavement. Over the coal are 4 feet of indurated fireclay, above which are 20 feet of rock. The pavement is composed of fireclay 6 feet thick.

Fig. 227 shows the method of working. The pillars are 20 yards wide by 30 yards long. The openings round them are 9 feet wide the short way and 12 feet wide the long way. The short way of the pillar faces the cleavage or cleat. The seam lies very flat, the dip being 1 in 20 to the North.

In the solid workings on a 12-foot wide place, a row of props or trees are set

up 5 feet apart, on each side of the roadway. The collier puts up these props, and he is obliged to place them so that they are not more than 5 feet apart, whether the roof is good or bad. The trees or props are $4\frac{1}{2}$ inches in diameter at the thin

Scale. 3 Chains to 1 Inch.

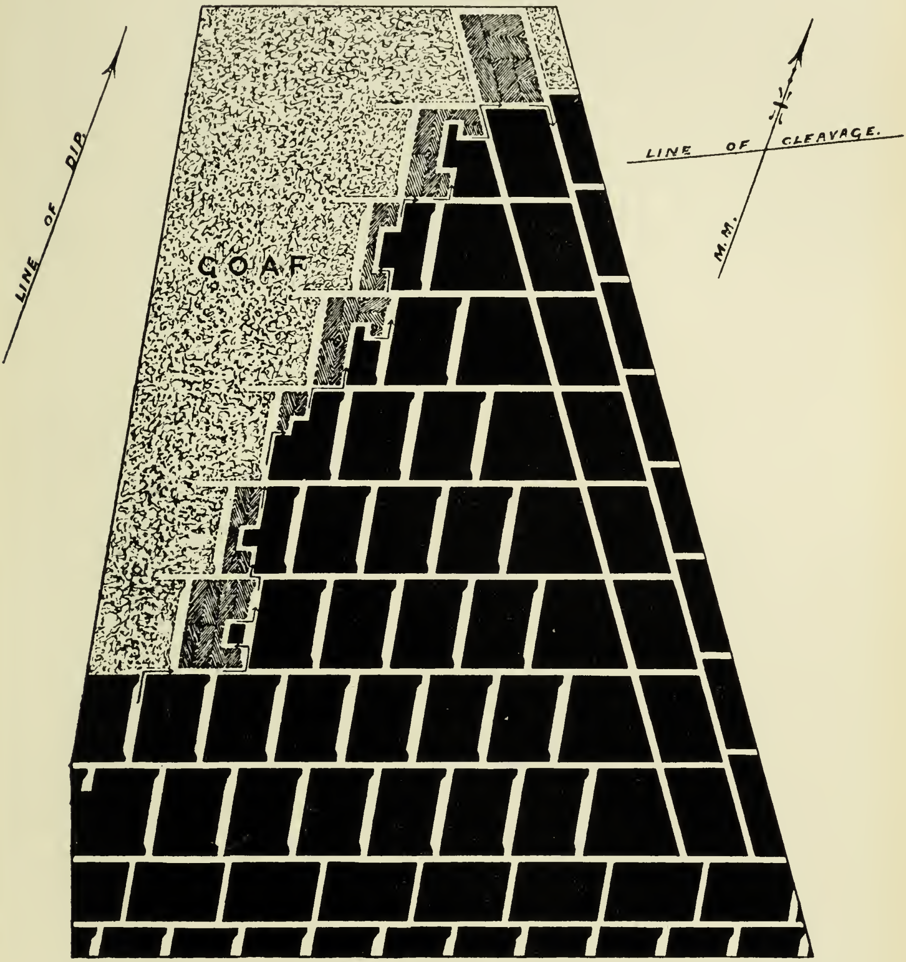


Fig. 227.—Allanshaw Colliery, Hamilton, Scotland. Plan showing Pillar and Stall Method of Working the Ell Coal Seam.

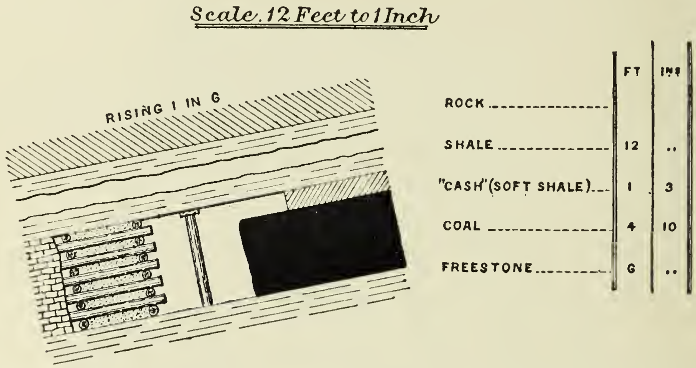
end, and cost at the colliery 7*s.* 3*d.* for 100 lineal feet. Two men work together in one place. Their practice, after the coal is holed, is to shear down one side of the coal and put a shot in the other, blowing out the coal. Open lights are used in the solid workings, and the colliers fire their own shots. They receive a tonnage rate for large coal, and another for dross or small, which includes payment for the timbering.

In the broken mine, the pillars are worked off in lifts of 5 yards. Three men work together in a lift. They hew the coal, place it in the hutches, and set up all

the timber. The colliers working off the pillars, or "stooping," as it is called in Scotland, use "Scotch gauze" lamps, and no blasting is allowed. The rails are laid in the road to about 3 feet from the coal, and a row of props set 3 feet apart, between the rails and the coal. On the waste side of the road are placed rows of props 14 inches apart, and about 3 feet between the rows. These trees are $4\frac{1}{2}$ inches in diameter and have small lids, 6 inches square and 1 inch thick, over them. Three men draw the timber from a lift, one of whom must be the fireman. In compliance with the Special Rules, he draws the props in the afternoon when his examinations are completed. Two of the men strike out the trees by blows from a hammer, whilst the third removes them to a place of safety on a timber tub made for the purpose. In a lift containing 300 trees, it takes about 3 hours to draw the timber.

At the Cowdenbeath Collieries, in Fifeshire, the Dunfermline Splint Coal Seam is worked on the Longwall system.

The collieries have been in operation since about 1851, the work at present being carried on at three shafts, the Nos. 3, 7, and 8. The last two are downcasts,



g. 228.—Cowdenbeath Collieries, Scotland. Section of the Dunfermline Splint Coal Seam.

and the No. 3 an upcast. The upcast is $\frac{1}{4}$ of a mile distant from Nos. 7 and 8 which are within 120 yards of each other. All the pits are of a rectangular form; No. 7, being 17 feet × 10; No. 8, 14 feet × 6; and No. 3, 14 feet × $5\frac{1}{2}$. The No. 3 Pit is 216 yards deep to the Dunfermline Splint coal, whilst No. 7 Pit is 270 yards deep to the same seam; and No. 8 Pit is 180 yards deep to the Lochgelly Splint and Parrot Seam.

A Guibal fan, 24 feet in diameter and 8 feet broad, is placed at the upcast shaft. It is driven at 60 revolutions per minute, and gives 50,000 cubic feet of air with 1·3 inch water-gauge.

Heavy pumping machinery is erected at both Nos 7 and 8 Pits. The No. 7 Pit pumping-engine raises 800 gallons of water per minute, and that at No. 8 Pit raises 600 gallons. All the shafts are used to wind coal in, the total landings being about 800 tons a day. In 1881 the following seams were worked at the No. 7 Pit: the Dunfermline Splint 4 feet 6 inches thick; Five-feet, 4 feet 8 inches thick; Mynheer, 4 feet thick; and the Lochgelly Splint and Parrot Seam, 12 feet thick. The strata dip to the North at an inclination varying from 1 in 6 to 1 in 3.

Fig. 228 shows a section of the Dunfermline Splint Seam. There are 4 feet 10 inches of coal. Resting on it are 15 inches of "Cash," or soft shale, used by the colliers to hole in. Above this is the roof, composed of shale, which is 12 feet

thick, and over this is rock. The pavement is freestone, about 6 feet thick. The shale over the seam makes a bad roof.

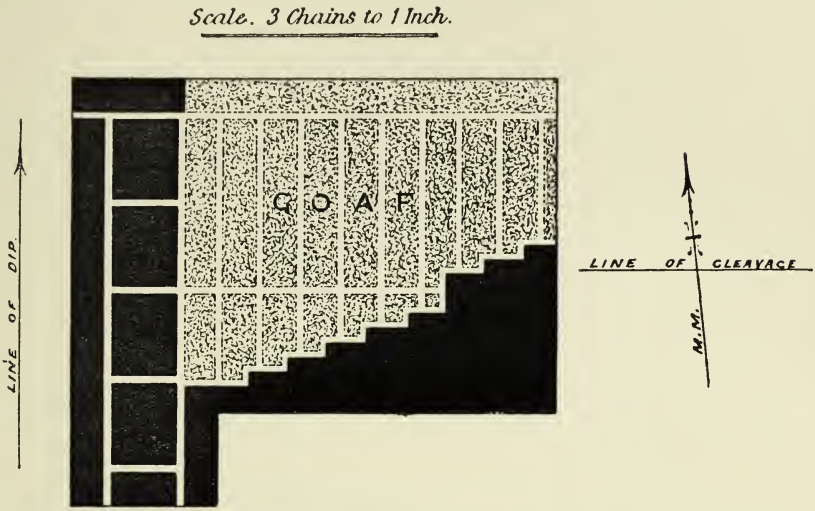


Fig. 229.—Cowdenbeath Collieries, East Scotland. Plan showing Longwall Working of the Dunfermline Splint Coal Seam.

Fig. 229 shows the method of working this seam. The levels are driven on end, or nearly parallel with the planes of cleavage, and the faces advance against the cleavage. The roads to the rise are driven at right angles to the levels, and they are turned every 14 yards from the level. Level roads cut off the rise roads every 60 yards.

The men draw the coals from the faces to the wheel-braes or inclines, thence they reach the shaft by self-acting incline planes. Cut-chain inclines (fully described in Chapter VIII. of this work) are used to let the coals down from the upper levels to the main wheel-braes.

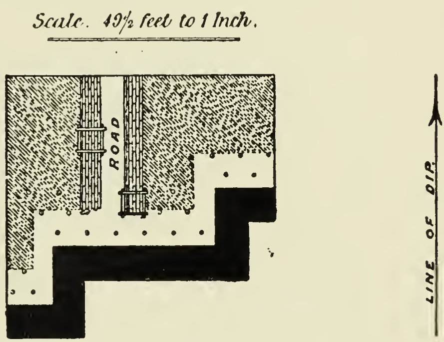


Fig. 230.—Cowdenbeath Collieries, East Scotland. Plan showing Face of Longwall Working in the Dunfermline Splint Coal Seam.

It is found better in working the seam, to step the wall faces, keeping them 5 yards in advance of each other as shown at Figs. 229 and 230, on account of the heavy bad roof. The weight is thus confined to the limit of each wall, and the roof settles down more gradually than when a straight line of face is kept.

Two men work in a place, and besides hewing the coal, they put up all props, chocks and build the packs. They send out about 5 tons in a day of 8 hours, and receive 2*s*. a ton on large or round coal. Powder is not used in working this seam. Under the direction of the fireman, the colliers set their props where they think they are most required, there being no specified distance between them. The roof is so bad that withdrawing the props is dangerous and

most of them are left in. The props are $3\frac{1}{2}$ inches in diameter, the lids over them being of broken props. The "cash" obtained in holing is used to build the packs, but it makes poor buildings, and, to strengthen the packs, chocks, 6 feet square, made of props and filled inside with rubbish, are placed on the sides of the roads, as shown at Fig. 230. When the roads are finished and abandoned, these chocks are taken out.

The fireman visits each place three times during his shift, and although he sets up no timber himself, directs the colliers to do so where he thinks they are necessary. The main roads are secured by props and sets of timber, or gears placed at no specified distance apart, but at distances considered necessary. The roof being bad makes the cost of timbering high. The cost per ton on round coal is 5*d.*, the price of pit timber at the colliery being 5*s.* per 100 lineal feet.

In the working of THIN SEAMS the most advantageous system is the Longwall, and an arrangement of roads should be designed to suit the inclination of the

Scale. 3 Chains to 1 Inch.

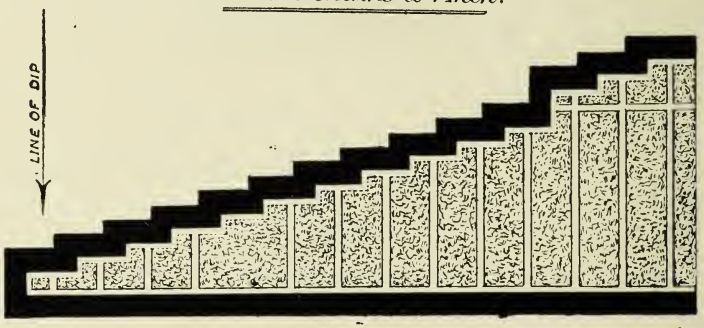


Fig. 231.—No. 1 MODE OF WORKING THIN COAL SEAMS IN NORTHERN FRANCE AND BELGIUM ADOPTED WHERE THE INCLINATION DOES NOT EXCEED THIRTY DEGREES.

seam or seams to be worked. The cost of working must of necessity be higher than in the case of thicker seams. Still, thin seams are successfully and remuneratively worked both in Great Britain and in other countries.

In Northern France and Belgium three different systems of working thin seams are employed.* No. 1 system, shown in Fig. 231, is an arrangement for seams in which the inclination does not exceed 30 degrees. Roads are carried to the full rise out of the chief level, the distance between these rise-roads being from 12 to 14 yards. The faces follow each other in step-like order, as shown on the drawing. At first the coal is taken down each of these rise-roads by means of a small self-acting inclined plane. When the faces have advanced a certain distance a new level is turned, which cuts off all the longer inclined planes, except one or two, which are retained as main roads. The lower level is at the same time advancing and opening out fresh ground, thus supplying more working faces. The main roads are ripped, and on the inclined planes tubs carrying 10 cwt. are used. A full description of the self-acting inclined plane in operation here is given in Chapter VIII. of this work.

No. 2 system, shown in Fig. 232, is suitable for seams whose inclination ranges from 30 degrees to 60.

In this case, a succession of faces, in step-like order, are driven. These faces advance in the direction of the strike of the seam, not towards the rise, as in the No. 1 system. Where the seams are so highly inclined and the face advances to

* See Transactions, North of England Institute of Mining Engineers, vol. XXVII., pp. 174–180.

the rise, getting the coal is attended with a considerable amount of danger to the colliers, as large masses of coal fall out upon them during their work. A considerable loss arises, too, from the fact that the loosened coal lying on the floor slips downwards towards the waste by its own weight, and portions become lost amidst the rubbish.

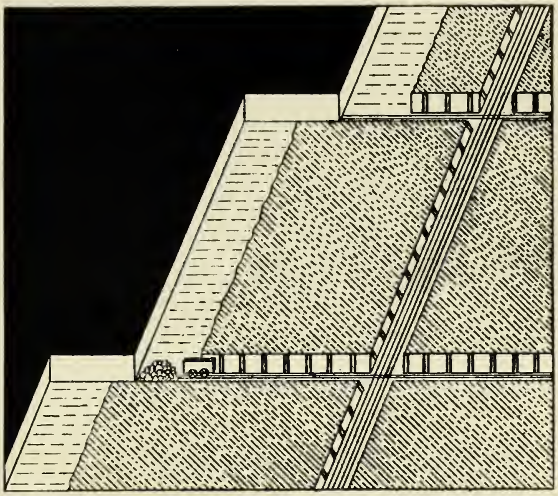


Fig. 232.—No. 2 Method of Working Thin Coal Seams in Northern France and Belgium, adopted where the Inclination ranges from Thirty to Sixty Degrees.

In the No. 2 system, however, the danger and loss referred to are avoided. A reference to the sketch shows that the tramway is laid along the main level, and any coal loosened by the collier, or accidentally falling, rolls along the face to the tramway, where its progress is arrested. It is afterwards filled into the tubs and sent out. Each face is 20 yards long (measured along the slope), and four men work in it. For their own comfort and convenience these men place pieces of board across the floor horizontally from prop to prop, by this means regulating and controlling the descent of the coal along the face.

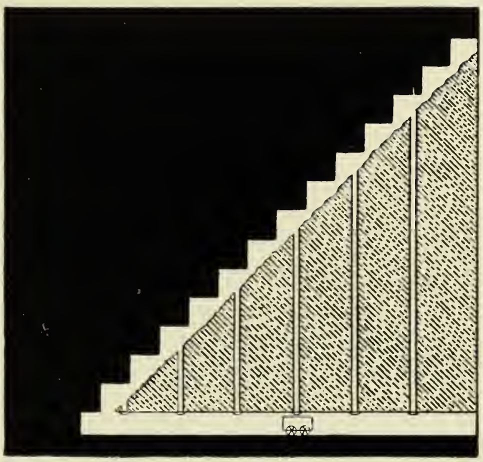


Fig. 233.—No. 3 Method of Working Thin Coal Seams in Northern France and Belgium, adopted where the Inclination varies from Sixty to Ninety Degrees.

No. 3 system is suitable for seams in which the inclination varies from 60 degrees upwards.

The work here is stepped out into a series of faces one above the other. Each face is 6 feet high, and forms the working place of one man, as shown in Fig. 233. In this arrangement of steps the lower workmen are in advance of the higher, so that each man is protected against danger of anything falling on him from above, by the ledge of coal projecting 6 feet behind where he is working.

The refuse yielded in working the seam and the inferior coal are thrown back behind the colliers, to fill up the waste. Where the seam does not yield sufficient rubbish to pack the goaf, the workmen stand upon scaffolds, formed by placing planks horizontally across the props.

The whole range of work consists of about a dozen steps, and at the bottom

there is a level road, to which the coals descend by means of small shafts or "chimneys." These chimneys are formed vertically in the goaf, by timbering with square frames and longitudinal poles, and are provided with a kind of sluice at the lower extremity. As the colliers hew their coal it is filled into the nearest chimney, to be afterwards withdrawn from below by the putters, who bring tubs under the chimneys, and for a time remove the sluice, thus allowing sufficient coal to rush into the tubs to fill them.

In many instances the seams of coal have been tilted over through more than a right angle, so that what are properly the floors of the natural beds have become the roofs.

As the floors are very friable, it is necessary to supplement the ordinary timber frames in the chimneys with poles, or lofting, and also with brushwood and wickerwood. This renders the cost of timbering high, sometimes as much as 1*s.* 7*d.* per ton. It is a matter of great difficulty to maintain the timbering in proper working order.

Excessively Thick Seams are often difficult to work, and require special methods according to the thickness of the seam and the inclination at which it lies.

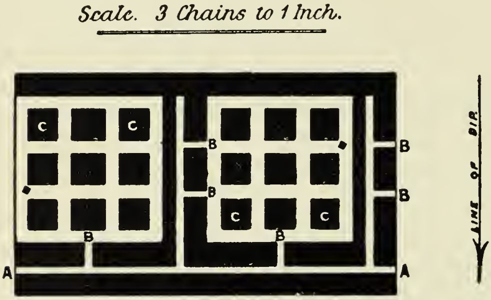


Fig. 234.—Plan showing South Staffordshire Square Work.
A A, Gate-road ; B, Bolt-holes ; C, Pillars.

In South Staffordshire, where the Dudley Thick or Ten-yard Coal Seam is found over a considerable area, a method of working called "Square Work" is sometimes adopted. The seam varies from 25 to 36 feet in thickness. The main road from the shaft, called a gate-road, is carried in the lower coals of the seam, and is ventilated by means of a separate air-head or drift of small dimensions, opened in the coal either to the side of or above the gate-road. From the gate-road (see Fig. 234) the main workings are opened, called sides of work, consisting of a square of 50 yards or more, with a narrow bolt-hole 8 yards long, connecting the gate-road and the sides of work. Stalls are then driven across and forward in the lower coals, leaving square pillars of about 10 yards in the side, to support the roof, and where the unsoundness of the coal or roof appears to require it, additional supports in men-of-war pillars of 3 or 4 yards square are left.

Sometimes these sides of work, instead of being 50 yards square, are larger, and in the form of a parallelogram, the longer side being parallel to the gate-road. To get the upper divisions of the seam, the men have to stand on the coal already cut, or on light scaffolding. As this process goes on, the rubbish and timber stop the communication to the first opened bolt-hole, and a narrow road is driven from the gate-road up the middle of the rib of coal between the two sides of work, and other bolt-holes cut through at intervals.

The pillars in the square-work are at the finish thinned till the roof falls, when the side is abandoned.

This seam being very liable to spontaneous combustion, dams are put into the bolt-holes to exclude the air from the small coal.

The coal seams of Dombrowa, in Poland, are of great thickness, and dip at a considerable angle. They form an extension of the seams of the Upper Silesian

basin at Zabrze and Myslowitz. The coal is dry, very inflammable, and unfit for coking. The slack is of little use, and is liable to give rise to spontaneous combustion. A special method is required to get the coal as large as possible. At

Scale. 3 Chains to 1 Inch

SECTION

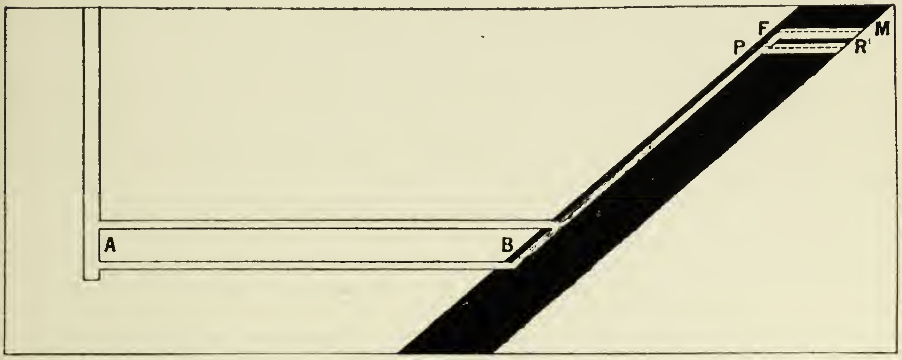


Fig. 235.

PLAN

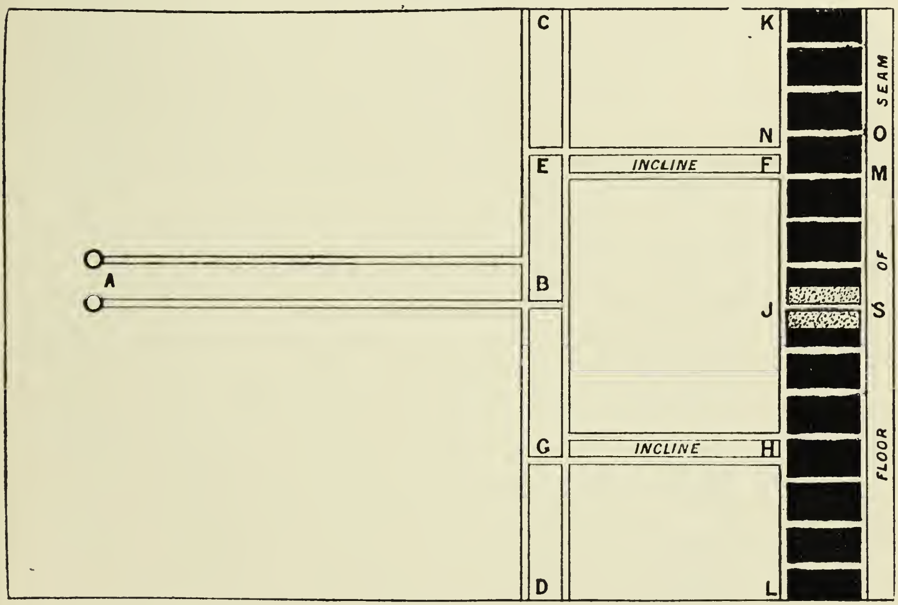


Fig. 236.

SECTION AND PLAN ILLUSTRATING THE WORKING OF HIGHLY INCLINED COAL SEAMS OF GREAT THICKNESS AT DOMBROWA IN POLAND.

Nowo Labenzky and Chieshkowsky the seam is from 52 to 59 feet thick, the dip varying from 15° to 40°. The method adopted at these places will be understood by referring to the accompanying section, Fig. 235, and plan, Fig. 236.

The seam is shown dipping towards the shafts at an inclination of 40°. From

the shafts, two water-level stone drifts, A B, on the section and plan, Figs. 235 and 236, are driven 33 feet apart vertically, which reach the coal seam at B. From this point the water levels are continued right and left along the course of the seam, keeping close to the line of intersection with the roof, and preserving their relative positions, B C and B D on plan. The higher one of these is used as a main drawing road, while the lower serves as a drainage and return airway. At intervals, varying from 260 to 360 feet, rise headings (B F on section and E F and G H on plan), are driven in pairs to the full rise of the seam and parallel to each other, about 23 or 26 feet apart, but of unequal section, the larger ones being afterwards converted into self-acting inclined planes, while the smaller are used for ventilation and as travelling roads, being deemed safer to traverse by the workmen than the main inclines. In driving these headings, a thickness of 3 feet of coal is left next the roof as shown on section, the roof over the coal seam being a black carbonaceous shale often very combustible, and even liable to spontaneous ignition.

From the top of the rise headings, F on section, and F and H on plan, a road is driven right and left on the roof side, F J, F K, and H J, H L on plan, and the coal is divided for working by driving headings across to the floor of the seam at regular intervals out of these roads, leaving pillars from 40 to 43 feet thick between the headings F M on section and F M, N O, &c., on plan. These headings crossing the coal seam are from 8 to 10 feet in height, the coal being worked in stages about 13 feet thick. A thickness of solid coal of at least 3 feet is left as a temporary roof to support the waste of the upper stage previously worked out, as shown between F M and P R on section. Working the pillars is commenced in the centre of the panel formed between any two of the inclined planes, after removing the roof coal by bringing back the pillars from S on plan in a direction parallel to the cross headings to J for a breadth and length of 20 feet and a height of 13 feet, the working face being protected by timber props. A part of the pillar working is shown at S J on plan. When the pillar has been worked off the timber props are withdrawn so as to allow the roof to come down, and if necessary, where the posts are tightly held, charges of dynamite are used to liberate them. Before removing the timber, however, a layer of small wood and props is placed on the floor, forming a kind of cushion, which distributes the pressure of the fallen rock and waste over the surface of the next lower stage. In this way the floor, which in due course becomes the roof of the lower stage, is sufficiently coherent to be kept up by the use of timber props.

It is usual to work three stages at different levels at one time; while the pillars are being removed in the uppermost, the headings are driven in the one below, and the roads corresponding to F J, F K of the first stage on plan, are being driven in the third out of the rise headings E F, and G H.

By this method the coal, being always supported on a firm bed, is not liable to crushing, and thus one of the principal causes of spontaneous combustion is avoided. In case of fire, the pillars, being only 40 feet wide, give facilities for extinguishing the fire. In order to obtain the full benefit of the method the excavations formed by the first four or five stages at the top should be closely packed, so as to have a protecting cushion for the workings against falls of rock from sides of the old excavations.

About 65 per cent. of the total quantity raised by this method is large.

In the coal mines of Upper Silesia, seams of coal varying from 20 to 30 feet thick are worked.*

The principal seam at the Königin Luise Mines near the village of Zabrze, near the frontier of Poland, is called the Schuckmann Flötz, and varies in thickness from 19 to 26 feet. At the Von Krug shaft it is 23 feet thick, is in one

* See Transactions, North of England Institute of Mining Engineers, vol. XXVII., pp. 190–193.

solid bed without bands or partings, and being of anthracitic quality is unsuitable for coke-making.

The method of working this exceptionally thick seam is shown in Fig. 237.

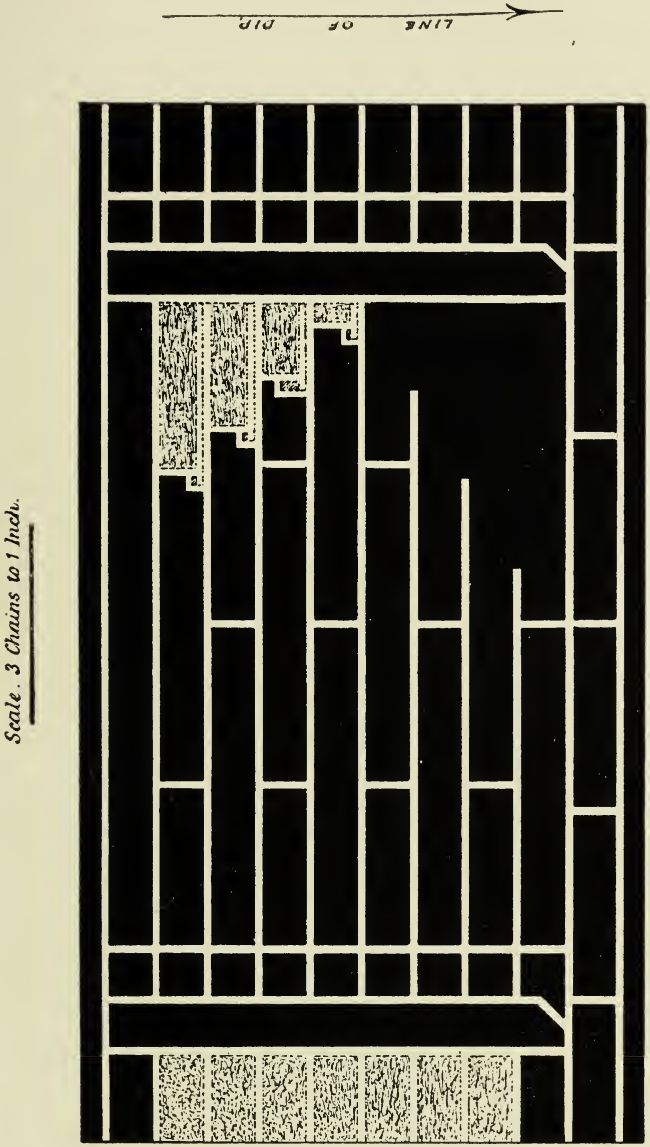


Fig. 237.—Plan showing Method of Working the Schuckmann Flotz Coal Seam at the K nigin Luise Mines in Upper Silesia.

It is first divided into blocks of 220 yards by 14, with the necessary cross-holings for ventilation, by driving a preliminary network of roads in the lower portion of the coal, viz., next the floor. These roads are driven 8 feet square in cross-section, and the pillars or blocks formed lie with their longer sides parallel to the strike of the seam. Two or three men, assisted by boys, work together in

each of these roads. The 220 yards by 14 block of pillars is next removed by taking a series of lifts 5 yards wide at a time, across the pillar, towards the rise, and taking all the coal to its full height of 23 feet. In order to get the coal, the colliers stand at different elevations on ladders, and the roof is supported by means of long timbering reaching from the floor to the roof, lofting being placed over the uprights. When a lift has advanced right across the pillar and is holed into the gallery beyond, it is finished, and as much of the timber as possible withdrawn. Two lines of these trees are, however, always left, one along the lower side of the lift, designed to protect workings coming from the dip against an influx of stones from the goaf, and another line up the near side of the lift, intended to give protection to the next succeeding lift.

Besides these precautions, it is frequently necessary to leave ribs of coal several yards in thickness, so that a considerable loss attends the working of this thick bed, besides which the coal left behind is liable to spontaneous combustion. Five men work together in a lift, assisted by three boys who separate the large and small coal by means of rakes, and fill it into the tubs, which they afterwards take out. It is the duty of the colliers to set the timber.

At the Mines at Kladno, in Bohemia, a thick seam of coal from 23 to 37 feet in thickness is worked.

The method of working in the first instance, is similar to that pursued in the mines of Upper Silesia. Here the preliminary network of roads driven in the lower portion of the seam, divides it into a series of large blocks, having their longer side parallel to the strike, the dimensions of each of which are from 60 to 100 yards long by 10 yards wide. The seam contains two bands of stone, one of which is 3 feet and the other 6 feet above the floor. The roads in the preliminary work are driven of the height of the upper band, and are, therefore, 6 feet high. A more intricate, but also more economical process of working the pillars, is practised than that adopted in Upper Silesia.

First, a stall, about 4 yards wide, is driven across the pillar, under the upper band, as shown in Figs. 238 and 239. The stall is not commenced at the extremity of the pillar, but a safety rib, of 2 or 3 yards in width, is left towards the goaf. This stall is rendered secure by timbering with stout 6-foot posts. After advancing across the pillar it holes into the road beyond, which is the goaf. The colliers then by a backward movement extract the safety rib, and also bring down the whole of the 20 or 30 feet of coal overhead. This is effectually done by removing the props with which the stall was timbered. When it is desired to bring down a quantity of top coal, firemen come to the stall and place cartridges of dynamite near to the top of several of the posts. The safety fuses attached to the cartridges are then lighted, and the men retire to a safe place. When the dynamite explodes, the posts are blown out, and the coal in the bed over falls with a tremendous crash. The colliers work in companies of two, and they have little more to do than fill the coal thus brought down: they can get from 15 to 20 tons a day.

Thick seams may also have the ordinary methods of Longwall and Post and Stall applied to them. The seam would be taken out in a number of different lifts formed of layers parallel to the stratification, the top being worked first and the roof allowed to subside on the coal. A 12-foot seam might be divided into two 6-foot lifts, an 18-foot seam into three, and so on. After an interval succeeding the working of the first lift the second might be proceeded with, but some time should be allowed to elapse between.

The author is indebted to the Council of the Mining Institute of Scotland for permission to extract from their Committee's Report "On Methods of Working and Timbering at the Face." The descriptions given of Celynen, Risca, and the

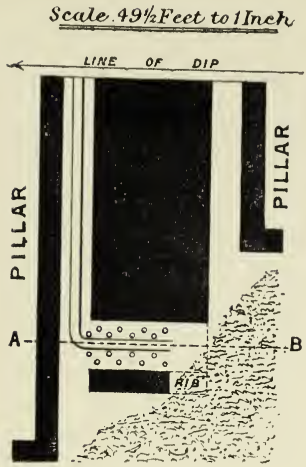


Fig. 238.

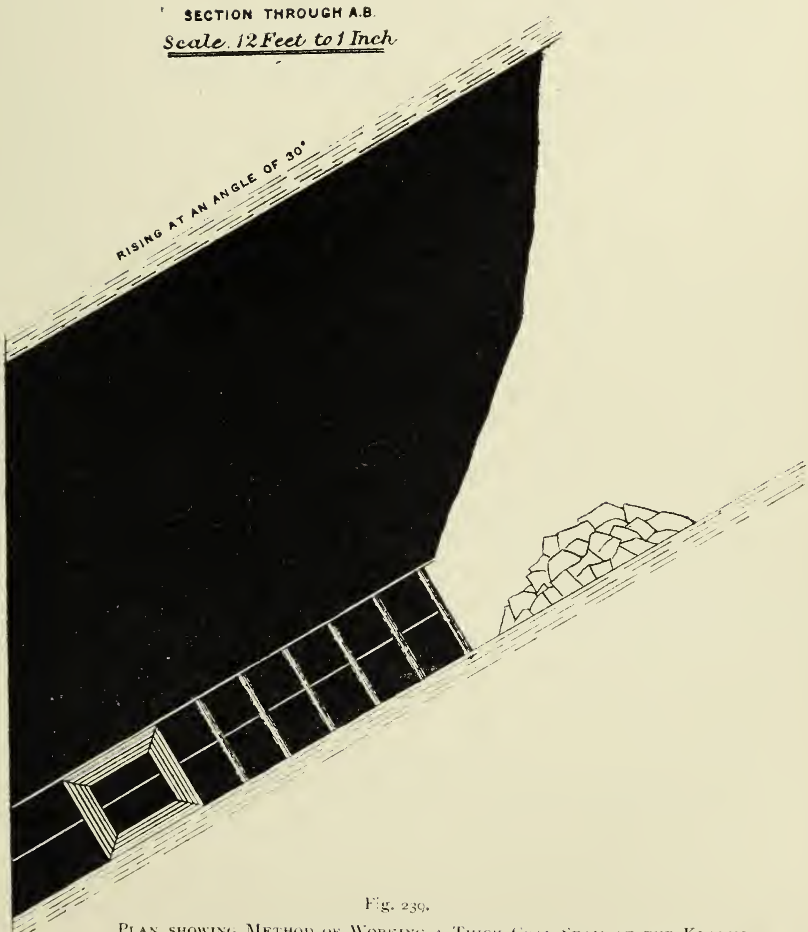


Fig. 239.

PLAN SHOWING METHOD OF WORKING A THICK COAL SEAM AT THE KLADNO MINES, NEAR PRAGUE, AUSTRIA.

Ocean Collieries, South Wales; the present method of working Lundhill, and Kiveton Park, Yorkshire; High Park, Notts; Wearmouth and Silksworth, Durham; Florence and Great Fenton, North Staffordshire; Cannock and Rugely, South Staffordshire; Pemberton, Lancashire; Clifton Hall, Pendlebury, Sovereign, near Manchester; Allanshaw, Hamilton, Scotland; and Cowdenbeath, Fifeshire, are extracted from their Transactions as given in vol. III. pp. 51 to 124.

This chapter will now be brought to a conclusion with a few questions and answers having reference to the working of coal seams, &c.

> *Question* 45. In a seam of coal worked by Longwall the coal is of a soft nature—whether would you work on plane or end? Why? How would you keep the weight off the face?

It is generally advisable to work coal of a soft nature on end, because it carries the weight better and is produced in better-shaped and larger blocks, while the roof is not so liable to fall, owing to the weight crossing the natural planes. To keep the weight off the face the back timber should be drawn.

> *Question* 46. Suppose you have a seam dipping to the South, and you meet with a downthrow fault on the East level, which way would you turn the road to get to the coal?

The road should be turned towards the North or in the direction of the rise as may be seen by the sketch, Fig. 240.

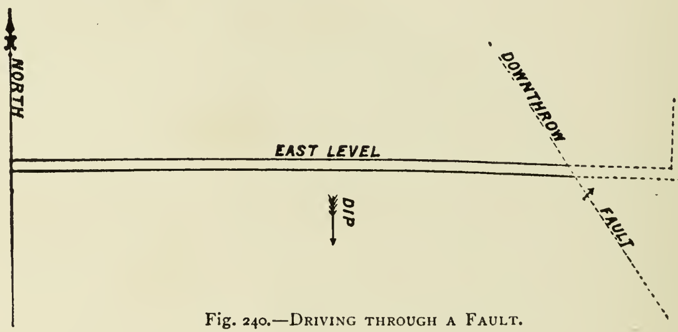


Fig. 240.—Driving through a Fault.

> *Question* 47. Suppose you have a seam dipping to the South and you meet with an upthrow fault on the East level, which way would you turn to get to the coal?

The road should be turned towards the South or in the direction of the dip, as may be seen by the sketch, Fig. 241.

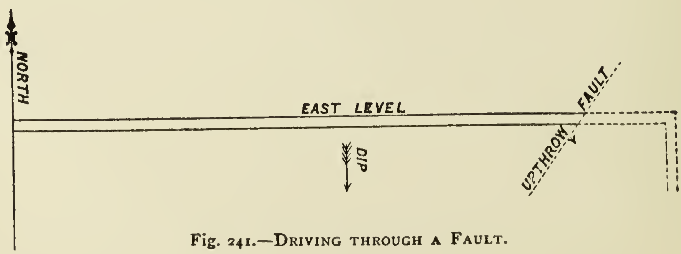


Fig. 241.—Driving through a Fault.

Question 48. In a road where the inclination is 1 in 7, a fault of 10 yards down is met with; what is the shortest length of level stone drift necessary to gain the coal?

The length of the stone drift would be 10 yards downthrow fault × 7 the dip of seam = 70 yards, and it may be driven either from the point where the fault was met with or from a point "out bye," as shown on sketch, Fig. 242.

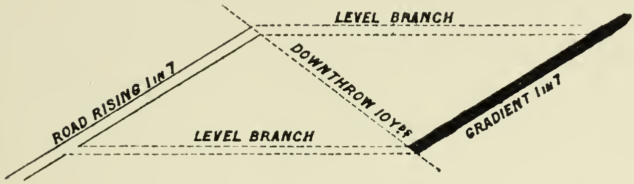


Fig. 242.—Driving through a Fault.

Question 49. In driving the West levels in a seam of coal dipping to the South at the rate of 1 in 6, an upthrow fault of 15 yards is met with, what would you do to recover the coal? If driven through, what length would the driving be?

I should drive in the direction of the dip or towards the South until cutting the coal, keeping the driving as truly water level as the West levels already driven were. The length of such driving would be 15 yards upthrow × 6, the dip of the seam, = 90 yards. See sketch, Fig. 243.

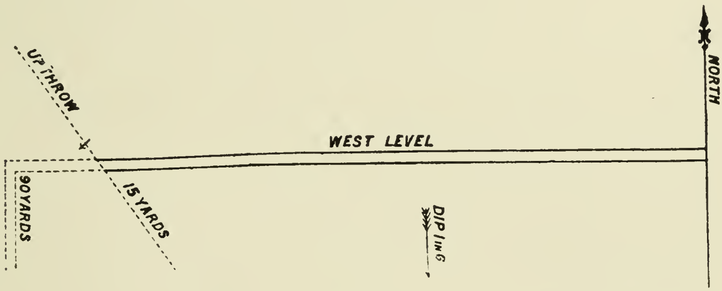


Fig. 243.—Driving through a Fault.

CHAPTER VIII.

UNDERGROUND CONVEYANCE.

Rails used on Main and Minor Roads—Construction of Tubs—Inclination suitable for Main Levels and Self-acting Inclines—Arrangement of Rails and Friction Rollers on Inclines—Blocks at the Bank-head—Ramean's Safety Catch for Inclined Planes—Mortier's Safety Catch—Method of Fixing the Incline Drum—The "Seizer" placed at the Foot of Inclined Planes—Accidents on Self-acting Inclines—Arrangement for Stopping Run-away Tubs down Inclines—Cut-chain Haulage on Inclines—Counterbalance Tram for Inclines—Different Systems of Engine Planes—Direct Haulage—Tail-rope—No. 1 Endless Rope—No. 2 Endless Rope—Endless Chain—Signals on Engine Planes—Size of Hauling Engines necessary—Compressed Air as a Motive Power—Compound Hauling Engines—Determination of Gradient for Horse Road and Inclined Plane—Calculating the Friction of Tubs.

Engine-planes, self-acting inclines, and other main roads are laid with heavier and longer rails than the branch roads, which are only used for limited periods in the workings. The heavier rails weigh from 24 to 40 lbs. per yard in from 12 to 18-foot lengths, laid on sleepers, generally of larch from 3 to 4 feet long by from 5 inches × $2\frac{1}{2}$, to 6 inches × 4. Within the last few years steel sleepers have been introduced very largely, especially on main engine roads, and have proved a great advantage. The rails in the workings are usually laid in 3 or 6-foot lengths, and weigh 16 lbs. per yard for small trams, increasing in weight where heavier trams are used.

The size of tub used will depend upon the height of the seam to be worked, and it may be made of wood, iron or steel. A very common form is to have oak framing below, the bottom and sides being made of $\frac{3}{4}$ of an inch or an inch oak or elm, the sides being strengthened by straps of iron. A drawbar of iron or steel passes the length from end to end, secured to the framing, and this bar has a hook at one extremity and a coupling chain at the other. If the tub has vertical sides, the wheels which are flanged are placed below, and are from 8 to 12 inches in diameter, but when the tub is narrower at the bottom than the top, the wheels may be set outside, and be from 15 to 18 inches in diameter. They may be made to turn on the axle or with it, the latter being the better plan if the roads are straight and the tubs are not run at a high speed, but where there are curves in the road, the loose wheels work better, particularly if a high speed round the curves has to be maintained. The axles are usually about $1\frac{1}{4}$ or $1\frac{1}{2}$ inches in diameter.

Fig. 244 shows an ordinary type of colliery tub with iron or steel-body, timber-frames, and cast-steel wheels and axles as made by Messrs. Thornewill and Warham, Engineers, of Burton-on-Trent.

The tubs are strongly, yet lightly made, and of a carrying capacity varying from 5 to 20 cwts.

The sides and bottom are connected by an internal angle-iron frame and the top edges are stiffened by a flat iron-frame, both being riveted to the body-sheets. The wood-frame is bolted to the body and provided with cast-iron open bottom chocks to receive the axles secured by bolts. A draw-bar and links for coupling tubs together are fitted to the frame. The wheels are of a special quality of cast-steel and secured to the axles.

Tubs are made by Messrs. Thornewill and Warham of various sizes and types to suit the requirements of the different colliery districts, some being wholly of

wood, with iron-bands and fittings, others are wholly of iron; some have closed ends as that at Fig. 244, others have one end open with two iron bars across.

In some districts tail-boards are used on the tubs in order to admit of filling and emptying them easily. Where tubs are subjected to heavy work arising from steep inclinations and undulations, or from passing through ill-kept, muddy and water-logged roads, the wear and tear are excessive, and necessitate frequent repairs. At collieries where these circumstances prevail, it is found more economical to have tubs made wholly of wood, with iron bands and fittings, being easier to repair than those having iron or steel-bodies which are bulged out of shape by getting off the rails and striking the rough and uneven sides of the roadway when in rapid motion on inclines, or elsewhere.

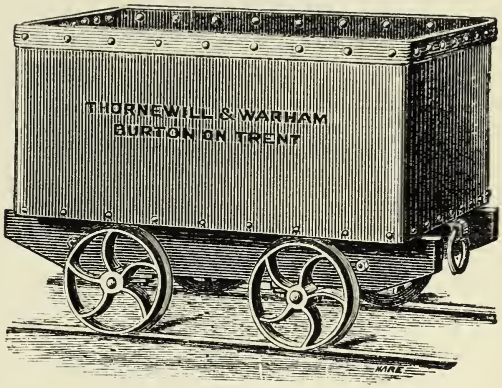


Fig. 244.—COLLIERY TUB.

For the removal of hot ashes from a ventilating furnace or boiler-fires under-ground, an iron or steel tub must be used.

To make the resistance equal in both directions along the main levels, assuming the empty tub to be 3 cwt., the loaded one 12 cwt., and the friction to be $\frac{1}{80}$ of the weight, the inclination would have to be 1 in 133. This rise would give the most advantageous effect to horse power, but it is usual to give a less inclination to the main levels, viz., about $\frac{3}{16}$ of an inch per yard, or 1 in 192, in order to win as much coal as possible to the rise of the levels.

The lowest gradient at which a self-acting incline will work depends on the state of the road and the load, but even under the most favourable conditions the

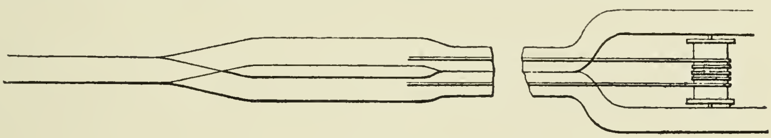


Fig. 245.—SELF-ACTING INCLINE.

gradient requires to be about $1\frac{1}{4}$ inches per yard, or 1 in 28. Tubs to carry from 6 to 9 cwt. of coal weigh about 3 or 4 cwt., and the larger tubs in proportion; they may be taken to weigh from $\frac{1}{2}$ to $\frac{1}{3}$ of the weight of coal they carry. The gauge of way varies according to the tub used from about 22 to 36 inches.

Where the output is large, and horses are employed, it is necessary to have two lines of rails on the main roads—at least for some distance from the shafts. Where there is only one line of rails, there should be good sidings at frequent intervals, which greatly facilitate the inward and outward tram transport.

Self-acting inclines may either have a double line of rails laid, or a single line from the bottom to the lower ends of the "meetings," from which suitable points are laid, leading to the double road, and at the top end of the meetings 3 rails are laid to the top of the bank, as shown in sketch, Fig. 245.

The advantage of the incline, as shown in the sketch, is, that a narrower road

will do for it throughout its course, except the "meetings," than where a double line of rails is used. This is sometimes important where the sides and roof are bad, or the incline is driven as a stone drift. A rope or chain may be used on the incline, but a rope is preferable, and a drum or a sheave may be used for it to run on. A drum is more suitable on steep inclines, unless the sheave has some gripping arrangement in the groove, such as Fowler's clip pulley. A brake for regulating the speed of the trains is applied to the ring on the drum or sheave, and may be a piece of wood fixed in a lever, or an iron strap gripping a half or the whole of the periphery. The rope may be in one, having 3 or 4 coils round the drum, and one end attached to the tubs at the bottom of the incline, and the other to the loaded ones at the top, or there may be two ropes on the drum, coiling in different directions. Friction rollers, to carry the rope, should be laid at intervals of 8 or 10 yards throughout the incline. In laying the rails, long sleepers are used above "meetings," to fasten the 3 rails to. At the lower end of meetings the points are of peculiar construction, being movable on a pivot, and are self-acting, the full train in descending placing them in proper position for the ascent of the next empty train. The full trains of tubs are thus placed alternately on each side of the incline. A common means of communication between the bottom and top

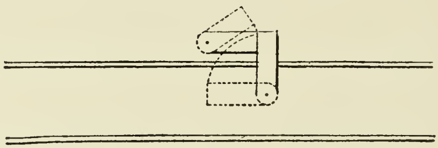


Fig. 246.—Bank-head Stops.

of the incline is by a rapper wire, having attached a hammer at the top and a lever at the bottom of the incline; when the rope is attached to the empty tubs at the bottom, the attendant there "raps" or signals to the attendant at the top, who, when the full train is ready, secures the rope at the end of the set, and lets it down. Blocks or stops are placed at the bank-head as a safeguard against tubs running down before all is ready. Fig. 246 shows one form of these blocks. They consist of two pieces of wood about 9 inches long and 4 inches square, each moving on an upright pivot. When in place, as shown by the solid lines on the sketch, Fig. 246, they form a stop to the loaded tubs coming out, and when the attendant wishes to let the tubs down the incline, he knocks the stops aside with a hammer, as shown in dotted lines, thus leaving the rails clear of the obstruction previously existing. For large trams stronger "chocks" are required.

More elaborate safety catches for inclined planes have been devised than the form of chock just described.

Mr. Ramean's catch consists of a bent lever, having two unequal arms, placed flat on the ground and turning round a vertical axis situate about its middle. It is placed parallel to the tramway and at such a distance that at least one of the ends always bars it, and the short arm is next the side of the inclined plane. As the empty tub reaches the top of the incline and passes forwards, its front wheel touches the long arm after the hind wheel has passed the short arm. The apparatus then blocks the way. When desired to have another run on the incline, the attendant, in pushing the tub upon the same tramway, is stopped by the bent arm, and before he can pass on with the tub, he must push the arm back with his foot. Each road must have a safety catch placed on it. It is stated to be cheap, simple, and effective.

Another safety catch is that of Mr. Mortier. It consists of an axle with attached levers, placed in the axis of the tramway and supported upon the

sleepers. The axle is movable, and in its two extreme positions, one of the two levers clears the tub axles, thus allowing the tub to pass, and in the other the same lever stops the tub axles. In the middle position assumed by the axle, both levers bar the passage of the tub. The empty tubs, in passing up the incline, work this catch automatically. This is done by sloping off the external edge of each lever, and the levers are thrown over by the axles of the tub. When the attendant wishes to pass a full tub downwards he removes the lever obstructing the way by means of a pedal provided with the apparatus. It is said that the catch cannot be put out of order either wilfully or by neglect.

The drum fixed at the top of the incline for the rope to coil on is supported in its position by timber. Two uprights are securely set in the floor and roof, and the drum turns upon bearings fixed in these uprights.

Besides the safety catches described, which are fixed at the top of the incline, an additional safeguard is a "Seizer," shown in Figs. 247 and 248, and this is

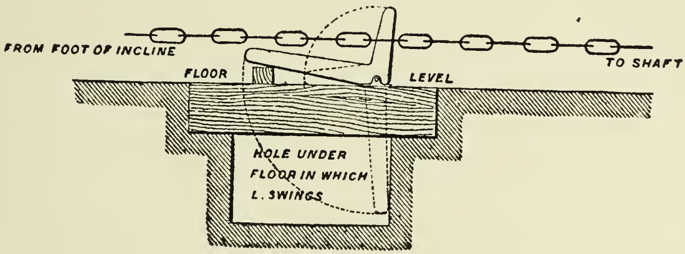


Fig. 247.—Seizer in Elevation.

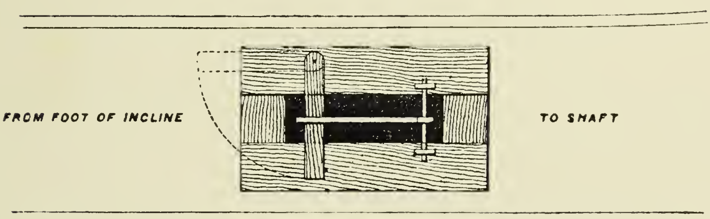


Fig. 248.—Ground View of Seizer.

placed at the foot of the incline. It consists of an iron arm bent in the shape of the letter L. This arm is carried by means of bearings from the point where it is bent. When in position to prevent a run on the incline, a bar of wood, which may be protected with strips of thin iron, is moved round horizontally at one end, the other being secured by an iron pivot round which it moves, until it assumes a position under the L piece, which may be held back with one hand during the operation. The horizontal portion of the L, on being let go, rests on the bar. A large link is placed in the middle of the short-linked chain at the end of the incline rope, and this link is now dropped over the upright portion of the L. This is done each time immediately after the descent of the full tubs, and the link remains on "Seizer" until the empty tram is attached. Should the attendant at the top, through any mistake, push the full tubs over the top of the incline with the rope attached before the empty trams at the bottom are ready, their further descent is arrested so long as the link remains on Seizer, as the bar under the L piece holds it and the chain at the end of the rope securely in position.

When the attendant at the bank foot has attached the rope to the empty trams, he gives the bar under the L a blow with a hammer, causing it to resume its position clear of the L shown by the dotted lines, Fig. 248. The L then drops into the position shown on the drawing in dotted lines in Fig. 247, and in so doing the large link of the chain falls free from the L piece. The attendant at the foot of the incline then signals to the top. As shown on the drawings, a slight hole is prepared under the floor level in which the L swings, and the bearings are carried on a slight timber frame prepared for it.

Many accidents occur at collieries where stops of the description shown in Fig. 246 are placed at the top of self-acting inclines, and these alone are relied on without the further safeguard of a "Seizer" at the bottom. The danger of this arrangement is increased where no regular attendant is placed in charge at the bank top, and where, consequently, each putter or twinboy (after reaching the bank top with the loaded tub he has brought from the workings), lets it down the incline. In some instances the loaded tub reaches the top of the incline by a road the inclination of which is not sufficient for the tubs to be spragged, and yet is too great for the putter to reach the bank head quietly without using considerable force in holding back the tub. In Somersetshire, the practice is to wear a rope band round the waist, from which hangs a short chain at the front of the wearer. A "crook" or short rod of iron with a hook at each end, bent in opposite directions like the letter S, is used to attach the end of the chain to the tub. On approaching the bank-head, as over other steep parts, if the road traversed is irregular in gradient, the putter hitches his crook and then holds the tub back, placing his feet (frequently naked) firmly against the sleepers to give him a foothold and considerable holding-back power. Frequently the stops, through forgetfulness, are not placed in position at the bank-head, and if then the putter reaches it as now described (having full confidence that the stops are rightly placed), the tub may pass these before he is aware of it, and directly afterwards continue over the brow of the incline, which perhaps has an inclination of 1 in 3, and anyhow is much too steep for the putter to longer control the tub he is attached to. Overpowered by, and unable to disengage himself from it, as the tub increases its speed, he is thrown from his feet and dragged along till the tub reaches the foot of the incline or is more quickly stopped by getting off the rails in the incline. Many fatal accidents from this cause have been recorded. Others occur from runaway tubs down inclines where the attendant omits to attach the rope at the top before knocking out the stops, and so causes an accident. Accidents on inclines may also be produced in other ways.

Figs. 249—251 show an arrangement which may under some circumstances be beneficially applied for guarding against accidents from runaway tubs down inclines, although no appliances of this kind are intended to supplant the care and vigilance which are essential at inclines as, indeed, at all other underground positions.

To an ordinary cross-bar, A, Figs. 249 and 250, are attached a strong pair of jaws, E. A piece of railway metal is then taken, the length of which should be about $1\frac{1}{2}$ times the height of the incline at the place it is to be fixed. A hole is drilled through the jaws, E, and also through one end of this piece of metal, a pin being afterwards passed through these holes. Through another cross-bar, D, is passed an eye-bolt carrying two swinging plates, C, and near the bottom of these plates is placed a cross-piece from one to the other on which the piece of railway plate, B, rests when up out of the way ready for use, see Fig. 251. A wire is attached to the bottom of the plates, C, which is carried to the bank-head a suitable distance from it. A lever is attached to the wire at the bank-head, by means of which, if the incline man should happen to let any tubs run down the incline without having attached the rope, he may by pulling it give motion to the plates C, which then take the position shown by the dotted lines, the consequence

is that the railway plate drops into the position shown by the dotted lines on to the middle rail of the incline, if the appliance is placed above meetings, or between the two rails if placed below meetings, thus effectually stopping the tubs from running any further.

The apparatus is simple, and may be placed in one or more positions on the

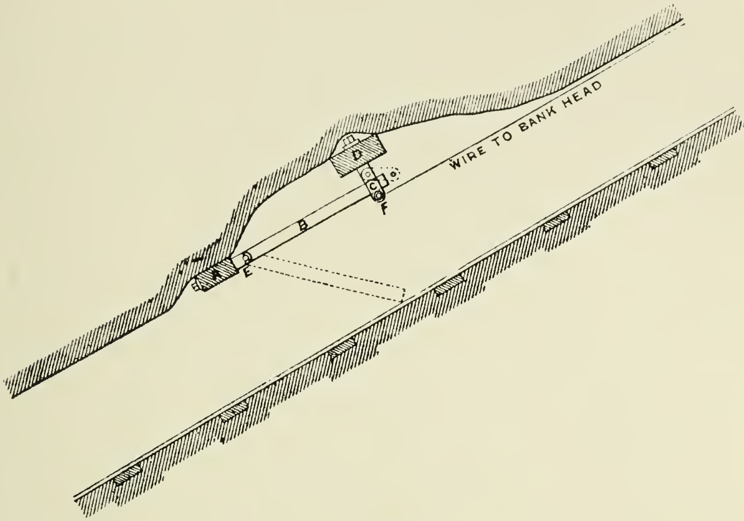


Fig. 249.

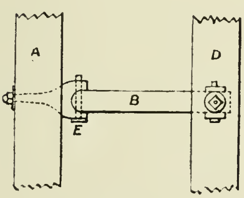


Fig. 250.

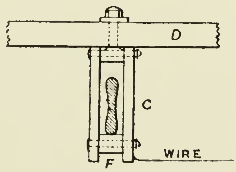


Fig. 251.

Arrangement to Stop Run-away Tubs on Self-acting Inclines.

incline, according to the length of it, and the same wire may communicate with all from the bank-head.

In Fifeshire a very curious arrangement of self-acting inclines is in force, called the Fife system of Cut-chain haulage on inclines. These "cut-chain inclines" cannot be worked advantageously unless the inclination is from 1 in 3 to 1 in 6, and it is found in practice that the greatest distance which will work effectively on a gradient of 1 in 4 is from 60 to 70 yards.

Where the system is adopted, the winning place which is to be the inclined plane, must be carried wide enough to have a double line of rails laid throughout. It is driven in the direction of full "rise," and level roads are turned out of it on either side every 15 yards. At the point of turning the level roads, a platform consisting of two cast-iron plates each 3 feet square is placed, to turn the tubs upon, and there are four movable rails for joining the lines on the incline when required.

Tubs may be run from the top of the incline or from any of the branch roads on the incline.

The method will be best understood by reference to the accompanying plan, Fig. 252. A main chain reaches from the bottom, F, to the top of the incline, passing round the wheel at B, and so far the system resembles the ordinary self-acting incline. Tubs may be attached to the main chain at B, and run in the ordinary way. In addition to the main chain, short or "cut" chains are

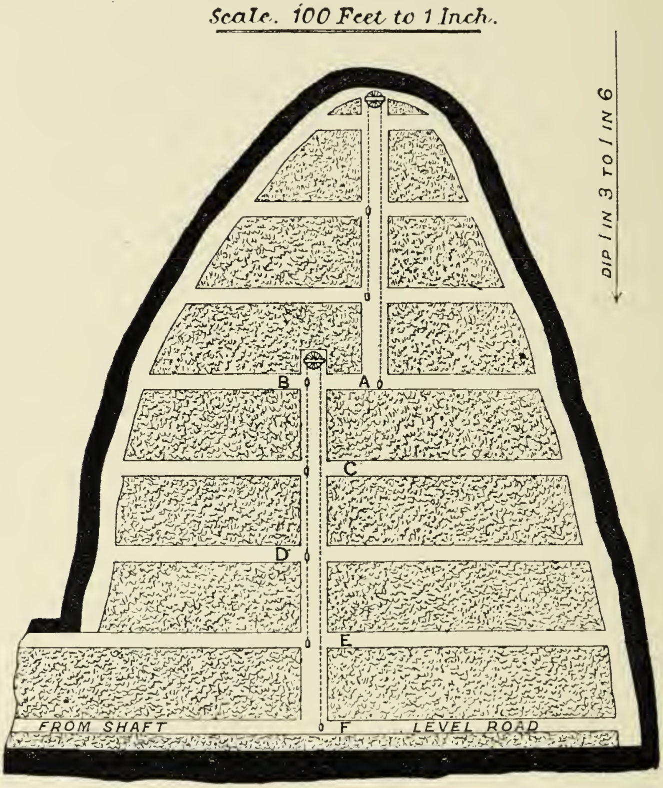


Fig. 252.—Fifeshire System of Cut-chain Haulage on Inclines.

used between the top of the incline and the different branch roads. The cut chains are shown on the plan, one from B to C, another from C to D, and a third from D to E.

If desired to run tubs from the top of the incline, the cut chains are not used, but rest on the floor between the rails. At each end of the main chain, and also at the lower end of each cut chain, is a link, see Figs. 253 and 254; and at the upper end of the cut-chains there is a hook shown in Fig. 255. When it is desired to run tubs from the branch, C, the hook of the cut-chain is attached to the link of the main chain at B, and the link upon the lower end of the cut-chain is connected to the draw-bar of the tub to be let down. After this connection, a chain is continuous from F to the top of the incline, round the wheel there and down to C. The movable rails on the incline at C having been lifted, the full tub is put over at C, and runs to the bottom F, the empty tub being taken up from F to the plates at C.

An even number of runs must be made from each branch at a time; 2, 4 or more may be made, but if only 1 or 3 be made the cuts cannot be put together

to allow the next branch at D to run, unless it be possible to put the "cut" across to the other side of the incline to be connected. The roadways being wide, frequently require a row of props between the two lines of rails, and where this is so, it prevents the cut-chains from being readily thrown across from one side to the other. By an even number of runs at a time the cuts may be easily adjusted for other branches.

During the time of the runs from C, the cut-chains between C and E, rest on the floor between the rails.

If desired to run from E, the cut-chain from D to E is attached to the cut, CD above it, which again is attached to the one, BC, above it, and the letting down is similar to that described at C. The same operation is required when running from the branch D.

When the heading or winning place has advanced 60 or 70 yards, it becomes necessary to set off either to the right or to the left, whichever may be most

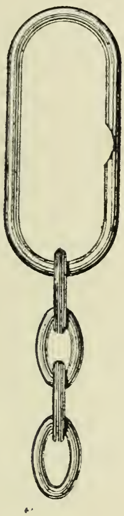


Fig. 253.

Fig. 254.

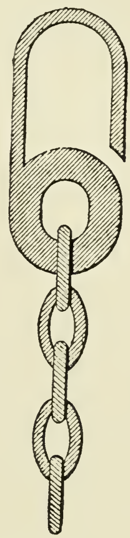


Fig. 255.

HOOK AND LINK USED ON CUT-CHAIN INCLINES.

convenient for siding room, and drive another incline at A. When there is a second incline, as at A, above the other, two tubs at a time may be run from F to B, to supply the incline A.

In order to regulate the speed of the tubs, a friction strap is fitted upon the wheel, and a wire attached to the handle is carried down the incline to the lowest branch, E, so that after putting over a tub at any branch road, the person in charge of it can stop it, or regulate its speed by pulling the wire which brings the friction strap into action.

On the Continent, where the coal seams are highly inclined, a somewhat curious arrangement of self-acting inclined plane prevails. It will be understood by reference to Fig. 256. The road is laid with four rails, the outer pair of which forms the gauge for a sort of tram, upon which is built a horizontal platform. Upon this platform the tub, whether full or empty, is carried.

The inner line of rails forms the gauge for another tram, which is long,

narrow, and heavy, and acts as a counterbalance. This counterbalance tram is made so low that it passes underneath the other at meetings. The two trams are attached to ropes which are wound on a drum placed at the top of the incline. The weight of the full tub in descending is sufficient to raise the counterbalance; the latter, in turn, being heavy enough to pull up the empty tub.

At large collieries for the most part, the underground conveyance is by means of engine planes. Although hand and horse putting may be very useful over short distances, and self-acting inclines work very economically, the circumstances of all collieries having long flat or dipping roadways leading from the shafts, or long roadways of varying gradients, demand some system of haulage by machinery. Few collieries are so favourably circumstanced as to require no haulage by machinery. In the improbable case of a pit sunk in the bottom of a basin, the haulage would be the cheapest possible. In most cases the coal has to be hauled a considerable distance, and in some for two or three miles. In many collieries a portion of the field lies below the level of the pit bottom, but may not admit of a road dipping uniformly all the way to reach it. Steam engines for underground conveyance may be placed underground, and the steam be either generated on the surface, and conveyed to them, or the boilers may be placed underground close to an upcast shaft. It is probably the better plan to have the boilers all together on the surface. The smoke passing up the upcast deteriorates the shaft lining, and it is obnoxious in a pit used for the ascent and descent of workmen. Moreover, it is highly objectionable to have large underground fires in a fiery mine, and a source of great anxiety in any. Whatever system of rope haulage is adopted, the engines may be placed either on the surface or underground, but the engine for driving an Endless Chain should be placed underground. A chain is about three times as heavy as a rope of equal strength, and it adds very much to the power of an engine to have the additional weight in a deep shaft. Another objection to chains being in the shaft is that they are more liable to break than ropes.

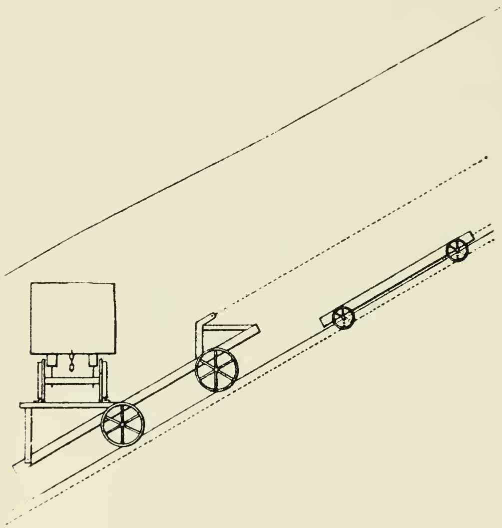


Fig. 256.—Counterbalance Arrangement of Self-acting Inclines in the Steep Measures of Northern France and Belgium.

Again, where compressed air is used as the motive power, this may be generated above ground and conveyed to the hauling engines underground. The system of haulage may be *direct* with one rope, which the weight of the empty tubs is sufficient to run back, or it may have a double line of rails, the empty train of tubs in that case slightly assisting the full train, or it may be by *tail rope*, which necessitates the use of two ropes, one to pull the loaded tubs out and the other to draw the empty tubs in. Then there is the *endless rope* system, which is capable of two applications, first with the haulage rope below the tubs, and

secondly with the haulage rope over or by the side of the tubs. There is also the *endless chain* system.

Direct Haulage.—To apply the direct system it is necessary that the fall from the shaft be more than 1 in 30 to overcome gravitation; it need not be a uniform dip, but no part of the road should have a less inclination than 1 in 28. The engines for hauling the loaded tubs up this incline may be placed vertically or horizontally: single or double engines may do the work: the drum or drums may be placed on the crank shaft, or may be on the second motion with spur wheels. The best form is undoubtedly a pair of horizontal engines, and if the speed required is great, the engine should work direct as in the ordinary coupled winding engines; but if the speed desired is low, the advantage of spur gearing is that it enables a smaller engine to do the work. A decision on this point will be governed somewhat by the speed of piston in the engine. Mr. Percy's rule is to allow a piston speed of 350 or 400 feet per minute for an intermittent haulage as this would be, but for one running continuously it should not exceed 250 feet

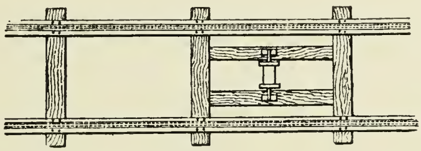


Fig. 257.—Friction Roller on Engine-plane.

per minute. A speed of six miles an hour on the average may be safely taken, and much higher, up to 10 or 15 miles an hour, if the roads and tubs are in good repair and properly maintained.

A single road only is necessary for direct haulage, though a double road may be used if desired, and friction rollers should be laid at intervals of 8 or 10 yards throughout its length to carry the rope. The timber on which the rollers rest should reach between the sleepers as per sketch, Fig. 257, and the height of the floor rollers must depend upon the clearance under the tub, which again will depend on the size of wheel used. Besides the floor rollers it will be necessary in going round curves to place either long rollers with their spindles set vertically or bevelled pulleys. If the dip "in bye" is not regular, but rather decreases, it will be necessary from the point at which the dip changes to place one or two roof rollers. On steep inclines worked by direct haulage, there is necessarily a great strain on the coupling chains and drawbars of the tubs and the capping of the rope. These should be made of the very best material and subjected to a careful and frequent inspection. The truest economy is to have ropes of the best steel, and all other materials equally good.

It is customary to place a "trigger" or bar-hook, sometimes called a "devil" and a "bull," behind the last tub of the full train. This is a kind of fork with one end firmly fixed on the back end of the last tub and the other end, which is pointed, trailing along the ground so long as the train is ascending, but if a detached or broken coupling chain or rope causes the train (or the latter part of it) to run backwards, the "trigger" is forced into the ground, thus arresting the further backward movement of the tubs. This arrangement applies only to the ascent of the full train, and is not applicable to the empty going down. A bridle chain may also be used, and this is a means of safety to both the upward and downward set. The chain is made fast behind the last tub going up (which will be the first going down) and is passed under the train of tubs to be securely connected with the hauling rope at the other end of the train. This chain hangs

loosely and does not come into operation unless a coupling chain becomes detached or breaks, or a drawbar breaks, thus severing the train, which in that case is almost immediately joined again by the bridle chain. The bridle chain is, of course, no protection in the event of a broken rope whether the train be full or empty, but there is far more liability to a breakage in the former, in which case there is the protection of the "trigger." A number of accidents occur every year on these inclines, and other travelling roads for the workmen should if possible be provided. In any case besides the refuge holes required by the Act of Parliament, a distinct light such as a red one, which in a mine worked by safety lamps may require to be a safety lamp, should be placed on the front end of the first tub of the full and of the empty train, as well as an alarm bell to sound continuously whilst the train is in motion, so that fair warning may be given of the approaching train both to the eye and ear of all on the incline. By direct haulage, coal may be brought from more than one part of the mine. Branch roads may lead off the main road at any number of places, but each one will require an attendant, if the work is great, to set the points and attend to the signals.

The Tail-Rope System.—This has the great advantage of being applicable to almost any condition of road, a single line of rails only being required. Although crookedness and irregularity of the gradient need not preclude the adoption of this mode, it is much better applied where roads are straight and have regular gradients. It gives great facilities for working branches.

The engine for working the "tail-rope" should be double and placed horizontally. It must have two drums, one for the main rope and the other for the "tail," and the engine is worked on the second motion, each drum being on a separate shaft and connected by spur gearing to the engine shaft. Each drum may be put in and out of gear by means of clutches worked by levers. The length of rope required to work any plane is three times the length of the plane, the "tail-rope" being long enough to reach from the front end of a train of empty tubs standing at the out-bye end of the plane to the "in-bye" end of the plane, where it is passed round a large pulley and reaches back along the plane to the drum of the engine. As the train of empties is drawn in, the tail-rope is wound on to its drum and the main rope (which is usually stronger in the proportion of 3 to 2 as compared with the tail-rope and must be the length of the plane) is run off the other drum, which is at the time out of gear. After changing the full for the empty train, the tail-rope drum is thrown out of gear and the main rope drum into gear, the engine is reversed, and the full train drawn out, to which is attached the tail-rope ready for the next empty train. The brake is usually applied to the loose drum gently, whether the train is going in or out. This prevents the rope from getting slack. The main and tail-ropes are carried by rollers and pulleys at intervals of about 8 or 10 yards apart. The branches worked off the main road (as well as the main road itself) have pulleys placed at the end of them round which a rope passes, its two ends reaching out to the main road; and on the train reaching the branch line, if desired the train may stop by signal, then be disconnected from the tail-rope at the front end of the train and a connection made with the branch line rope. There are different ways of making this connection, as seen by the following three sketches, Figs. 258, 259, 260.

In Fig. 258, a wheel is fixed near the roof or under the rails, and one end of the branch rope is brought round this wheel, shown at D. When the train is to be sent into the branch the rope end A replaces B at the front end of the train, and the end D replaces C on the tail-rope. This method requires a winch to pull the branch rope properly in place. In Fig. 259 the end E replaces F, the tail rope is left entire, but being disconnected from the train at F, is brought a little further by the engine and connected to G. This method does not require a

winch. The plan shown in Fig. 260 is perhaps the simplest, and in it the position of the ropes is so arranged that when the full train reaches the shaft the shackles on the main and tail ropes are just opposite each other at the branch

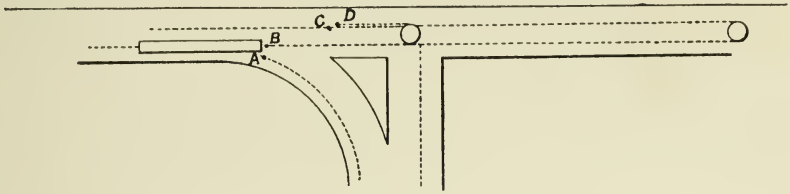


Fig. 258.

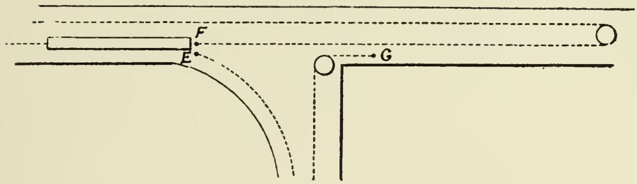


Fig. 259.

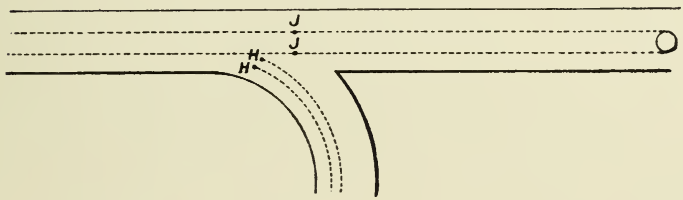


Fig. 260.

Connection for Ropes between Main and Branch Roads.

end, when the two ends J J are changed to H H by the attendant at the branch end.

The change is quickly effected by means of shackle joints on both the main and tail ropes. In Fig. 261 the pin P secures the shackle. At its lower end a thread is cut for screwing through the under side of the shackle. The attendant

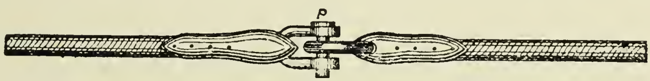


Fig. 261.—Shackle Joint for Connecting and Disconnecting Ropes.

uses a key fitting the head of the pin, which he readily withdraws by turning it a few times. In some instances the heads of the pins are sunk in the shackle when screwed home, and then the heads have central square recesses formed in them about half-an-inch deep. The attendant withdraws the pins by a suitable key which fits the recesses in the heads.

Where the plane has no branches, only one set of ropes will be required. On very short sharp curves a single sheave for each rope will be sufficient to prevent their touching the side, but where the curve is of large radius a number of sheaves or rollers must be placed. From 30 to 60 tubs form a train for the tail-

rope system. The connection between the train of tubs and the ropes is made by some form of knock-off link, one being shown in Fig. 262. When it is required to disconnect the rope, the cottar A is withdrawn, and the link pushed over by the hand or foot. Where the rise from the shaft is suitable for the loaded train to run out with the rope attached, a tail-rope only need be applied for drawing the empties in, and no main rope would, of course, in that case be required.

The Endless Rope Systems.—The Endless Rope is divided into No. 1 Endless Rope and No. 2 Endless Rope systems.

No. 1 is a modification of the Tail Rope system. The rope has to be kept

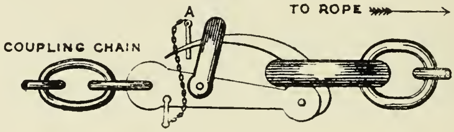


Fig. 262.—Knock-off Link.

constantly tight, and this may be done at any convenient point by passing it round a pulley fixed upon a tram, to which a hanging weight is attached (Fig. 263); or the hanging weight may be replaced by a tram working on a short incline, and loaded sufficiently (see Fig. 264). Motion to the rope at the other end is facilitated by a deep-grooved pulley (see Fig. 265), or by a pair of

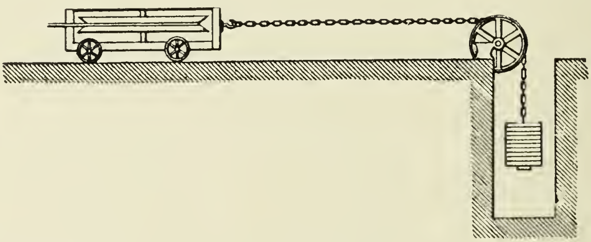


Fig. 263.—Tightening arrangement for No. 1 Endless Rope Haulage.

ordinary large pulleys after taking the rope two or three times round each to cause friction. There are several ways of attaching the trains of tubs to the rope (which in the No. 1 system runs under the tubs) by a socket in the rope, and a short attachment chain (Fig. 266), or some form of clamp for gripping the rope.

The mode most commonly employed is that of having a bogie provided with a pair of grips, with which the attendant seizes the rope as required. In this case a train of tubs is taken at once.

A very effective haulage-clip is Hanson's. It is made in two types by Mr. Isaac Hill, George Street Iron and Brass Works, Derby. Figs. 267 and 268 show this clip as adapted for the bogie, whilst 269 and 270 show the form of clip suitable for attaching a single tub or a train of tubs to the rope.

The mode of adapting the clip to bogies, or the present existing bogies, will be seen by Figs. 267 and 268, which is done by very simple means, and at the same time will be noticed that the working of the clip is most effectual for roads of any reasonable gradient.

In the bogies there are fixed two bars of wrought iron, B and D, Fig. 268, 12 ins. apart from each other, and the clip being 9 ins. on the clipping or

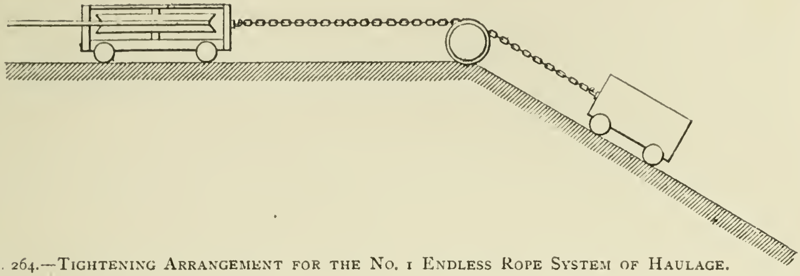


Fig. 264.—Tightening Arrangement for the No. 1 Endless Rope System of Haulage.

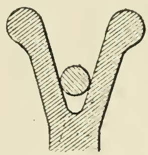


Fig. 265.—Deep-grooved Pulley for Endless Rope Haulage.

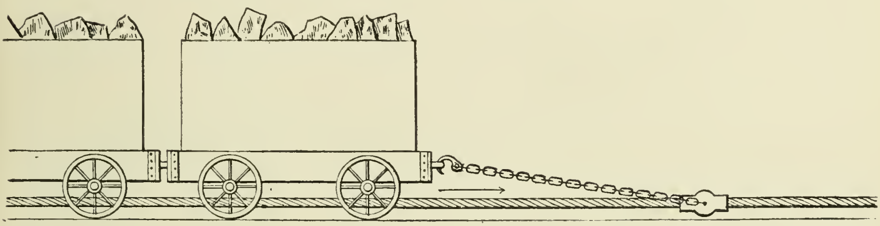


Fig. 266.—Under Method of Tub Attachment to Endless Rope applied at one or both Ends of the Train.

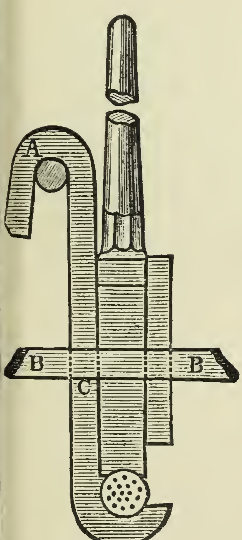


Fig. 267.

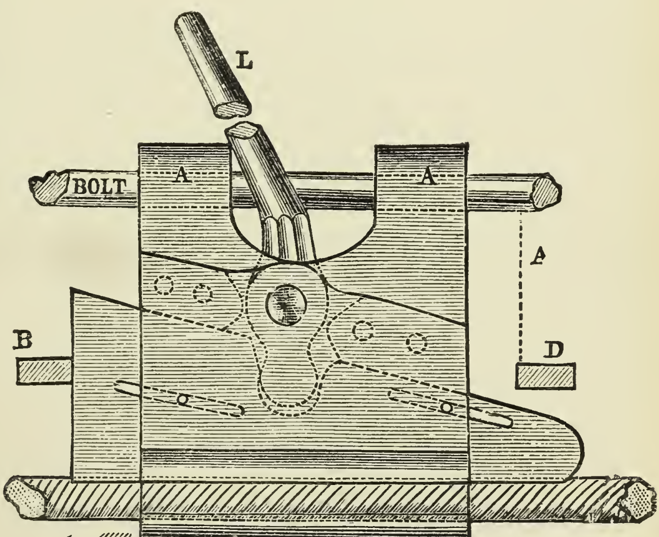


Fig. 268.

Hanson's Haulage Clip for Bogies.

gripping part, gives 3 ins. of space for the clip to move from one bar, B, to the other bar, D. (Note the distance on Fig. 268 from the bar D to clip.) The clip is suspended on a 1 in. round iron bolt or pin at A A, Fig. 268, and in section of same at A, Fig. 267; and as the gradient of the road alters, the whole clip will slide backwards and forwards upon the bolt or pin, till it is prevented by one of the bars, B or D, Fig. 268.

The clip is represented to be drawing or shunting a load up an incline or on the level in the direction of the arrow on Fig. 268, and it will be noticed that the

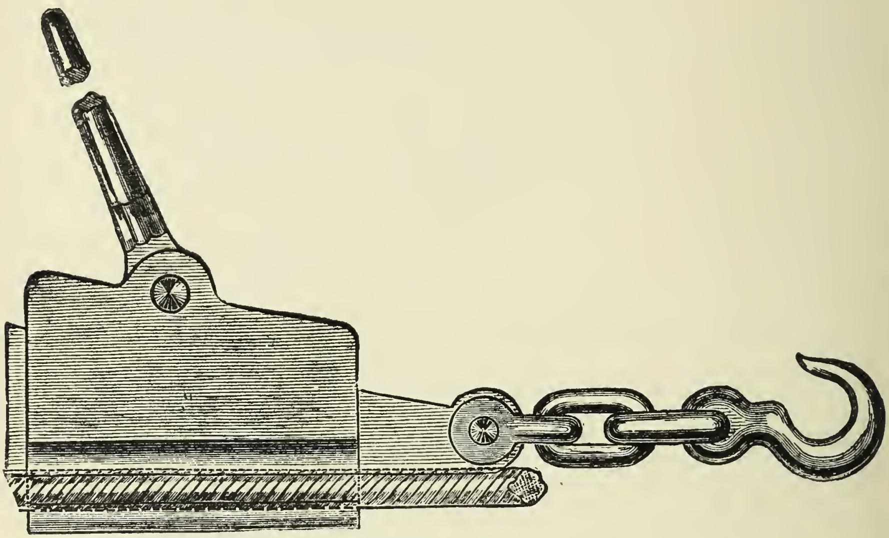


Fig. 269.—Hanson's Hand Haulage Clip.

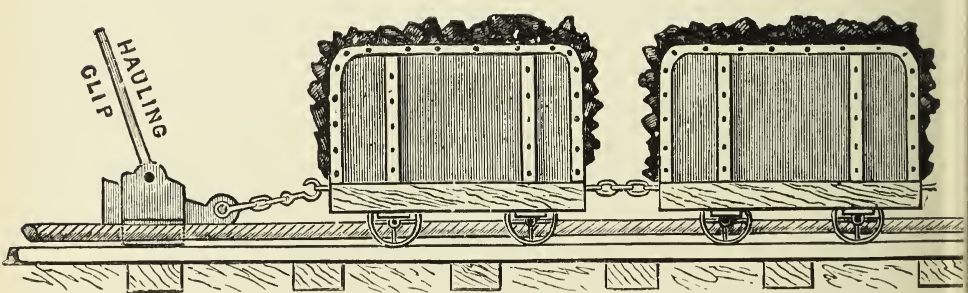


Fig. 270.—Hanson's Hand Haulage Clip attached.

greater the load or the greater the resistance the tighter the incline block will be forced upon the rope. Should the gradient of the road alter to a descent, the resistance being taken off the bar in the bogie at B, the tendency of the load will be to hasten on at a greater speed, thus causing the clip to slide back upon the bolt or pin at A A, Fig. 268, till it arrives at the bar, D, in the bogie and dotted line A to D, Fig. 268, thus holding back the load and preventing it from obtaining a speed greater than that of the rope. The bar, D, pushing against the body of the clip, tends to force the wedge upon the rope as did the bar, B, when it was on the wedge. The operator lifts the rope into the groove at the lower part of the

plate, C, Fig. 267, and at pleasure brings down the incline block by means of lever, L, Fig. 268, which block grips the rope as in the hand-clips, the load being at once set in motion.

The bolt or pin acting as a centre for the clip to rotate upon, the latter can be moved at the will of the operator.

This bogie clip is found to be very effectual and sure in work, and can be used by a boy in the pit.

Hanson's hand-clip is shown at Figs. 269 and 270. It will pass round curves very easily in its inward and outward journeys, the lower part being made to suit the groove of pulleys.

The gripping part of the clip being 7 inches long, it holds the rope firmly without exercising a cutting or tearing action on it. The greater the load, the tighter the clip holds the rope. It is easily handled, and can be instantly disengaged by a boy.

Fig. 271.

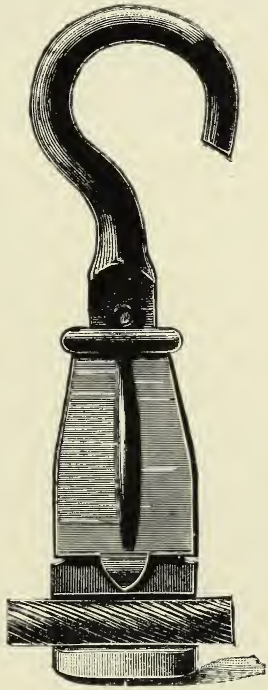


Fig. 272.

HUMBLE'S HAULAGE CLIP.

Mr. Stephen Humble's haulage clip is shown at Figs. 271 and 272. It is not adapted for bogies, but is simple in construction and allows of easy attachment to, and detachment from, the rope while in motion. No damage is done to the rope from its working.

A single or double line of rails may be used, but when single the rope works backwards and forwards, instead of continuously round in one direction; one part of the rope is on the road, and the other runs at the side. With a double line the rope works continuously round in one direction, the empty tubs go in on one line, and the full ones come out along the other. Friction rollers are laid at intervals for the rope in the case of a double line in the middle of the roads, and in the case of a single line along the middle of the road and at the side. The amount of rope required to work this system is, of course, less

than by tail rope, and the rope lasts longer. By suitable arrangements at the junctions branch roads can be worked, an attendant disconnecting the tubs while passing round the turn, where the wheel of the branch is fixed. It works on an undulating road, and where there are curves of good radius.

The No. 2 Endless Rope system, where worked similarly to the Endless Chain system, requires a double line of rails. The rope, instead of being under the tubs as in the No. 1 system, rests upon them, they being attached to the rope either singly or in trains of tubs varying in number from 1 to 12, and they are placed at regular intervals apart.

Some modifications of the No. 2 Endless Rope have been tried, such as carrying the ropes at the sides of the tubs instead of over the centre, and also by using a single line of rails with a suitable arrangement of pass-byes. These modifications do not generally work so well as the system itself, and require special conditions for them to work at all. If the engine plane has curves in opposite directions the rope at the side tends to pull the tubs off the way, and consequently empty tubs at the curves leave the metals. Again, the opposite

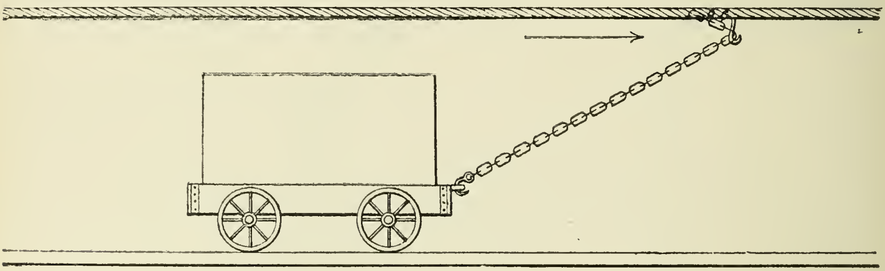


Fig. 273.—Over Method of Tub Attachment to No. 2 Endless Rope applied at either one or both Ends of the Tub or Train.

curves in a roadway give considerable trouble to a single road with pass-byes, although this modification may work fairly well in a straight engine-plane with a uniform gradient, or where the curves are all in one direction, and a regular supply of tubs can be arranged to suit the pass-byes.

Motion is given to the rope, which is fixed much in the same way as No. 1 Endless Rope. The speed of rope in the other systems described is fast, from 6 to 10 miles an hour, but with the No. 2 Endless Rope a slow speed of about $1\frac{1}{2}$ miles or 2 miles an hour is given to the rope. Branch lines, curves and undulations in the road can be overcome, but the fewer curves and undulations the better. There are two methods of connecting the tubs with the rope. In either case chains are used. One method consists in fixing one end of the attachment chain to the coupling chain of the tubs, throwing the other end over the rope which is in constant motion; then coiling it 2 or 3 times round the rope, and securing it to the hook at its end. If the road is undulating it will be necessary to put another chain in a similar way at the other end of the tub or tubs (see sketch, Fig. 273).

In the other method, instead of the chain being coiled round the rope, strong loops of hemp 1 inch in diameter are fastened at intervals along the rope by a wrapping of string. One hook of the chain is first attached to the tub, and the hook at the other end is then passed through the loop on the rope. This is not so applicable on an undulating plane where tubs are put on singly, as it would be necessary to put an attachment chain at each end of every tub, which would mean a great number on the rope altogether. Where applicable it is a more expeditious method than the former (see sketch, Fig. 274).

It is evident that where the coal is loaded up above the top of the tub, unless the roads are high, this system cannot be adopted. In working branch roads by the No. 2 Endless Rope system, it is necessary to dis-connect and re-connect every chain used in attaching the tubs to the rope, and the arrangement of pulleys to work a branch road is shown in Fig. 275. Each branch must have a separate tightening apparatus. The upper pulley has a clutch-box, and may be thrown out of gear if it is not desired to work the branch line. The rope is passed round the driving pulleys two or three times, the trod being shaped to receive it. If the engine is placed on the surface the rope passes over a pulley at the top of the pit,

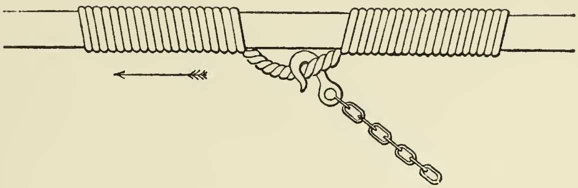


Fig. 274.—Over Arrangement of Attachment to No. 2 Endless Rope applied at either one or both Ends of the Train.

and goes down the shaft to another pulley at the bottom placed at right angles to the one on top, and if there are a number of branch roads at the pit bottom to be worked the rope is coiled round other pulleys fixed in position to work those branch roads. It is then brought back to the pit bottom, where another pulley

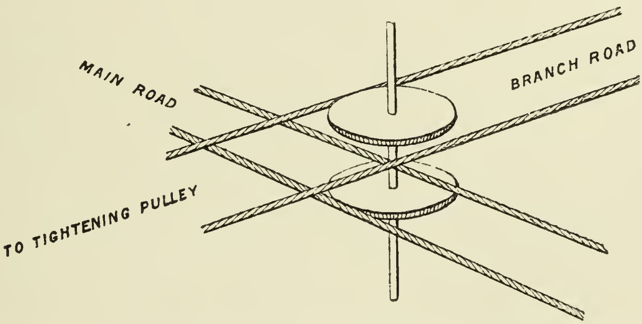


Fig. 275.—No. 2 Endless Rope System of Haulage. Arrangement of Ropes for a Branch Road.

guides it up the shaft; it then passes over another pulley at the pit top to the driving pulley at the engine. From each of the main roads leading from the shaft branch lines may, if required, be worked. Two branch lines may be worked opposite each other off the main road by having three pulleys on the vertical shaft instead of two as shown in the sketch, and other branch lines may again be worked off these. In the case of two branch roads working opposite each other off the main road, the tightening apparatus for each branch would be placed at the in-bye end, instead of as shown on sketch. An engine placed on the surface can be made to work an endless rope at another level in the shaft in addition to those at the pit bottom. There is no "runrider" required in this system as in No. 1, and the speed of the ropes tends to their duration.

Endless Chain System.—The Endless Chain System is somewhat similar to the No. 2 Endless Rope, and a double line of rails is always requisite in its

application, one for the full, and the other for the empty tubs. The chain may be passed 3 or 4 times round the driving-wheel, which consists of an ordinary sheave, round which a piece of boiler plate about 10 inches wide is fixed, and to this are attached about 12 steel or iron "feet" on which the chain rests without touching the plate; or forks a few inches apart may be fixed in the trod, the chain then only passing half-a-turn round the wheel. The driving-wheels are placed horizontally, and motion conveyed from the engine to them by bevel gearing. The return wheels are ordinary sheaves, round which the chain passes half-a-turn. No tightening arrangement is needed, for the chain rests upon a fork in the tubs, which are always placed singly on the chain at distances varying from 10 to 40 yards apart, and it is better not to have them further than 30 yards apart, so that there may be no danger of the chain touching the floor. The

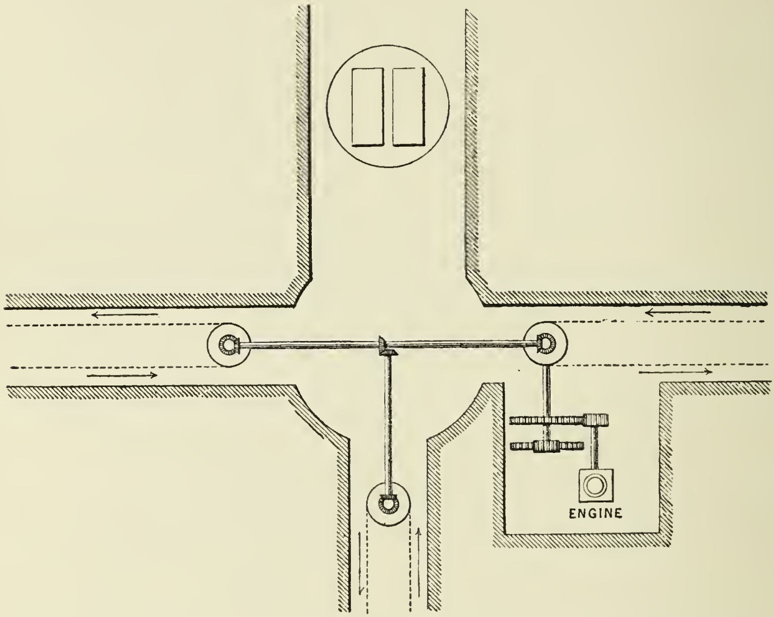


Fig. 276.—Endless Chain Haulage. Arrangement of Bevel Gearing from Hauling Engine to Roads leading from Pit Bottom.

speed at which the chain is driven varies from 1 to 4 miles an hour. Owing to the low speed of the chain, the condition of the rails is not of so much importance as with the Tail Rope and No. 1 Endless Rope, where the speed is greater, but care is required at the termini in the formation of the roads. On the "coming off" side the way is made to rise a few yards from the terminus, in order to obtain such a fall as will enable the tub, on leaving the chain, to acquire an impetus which carries it off the road; on the "going on" side the way is made to dip from the terminus, so that the tub may run to the chain without the aid of manual labour. Fig. 276 shows the arrangement of working roads leading in different directions from the pit bottom.

Every principal chain has its separate pulley and upright shaft, with bevel gearing at the top, and catch-box to put in and out of gear. All of them may thus be at work together, or any of them thrown out of gear at will. The handles to work the catch-boxes may be placed at each wheel, or they may be all placed together in the engine-house or elsewhere. Branch lines form no obstacle to the

successful working of the endless chain. There are two ways of working these. A double pulley may be placed opposite the branch similar to that shown at Fig. 275 for working No. 2 Endless Rope branch. The main chain passes round one pulley, and the branch chain takes its power from the other, which has a catch-box arrangement for throwing into and out of gear. Another and perhaps better way is to have three chains and three pulleys connected by gearing, as shown in Fig. 277. This leaves the landing-place clear for tubs.

The end of the tub on which the fork is placed is made to go last in starting up-hill, but in going down-hill it is placed first. Where the coal is not loaded up above the level of the top of the tub, the fork for the chain forms part of the tub, the groove for the chain being about an inch wide. One form is shown at

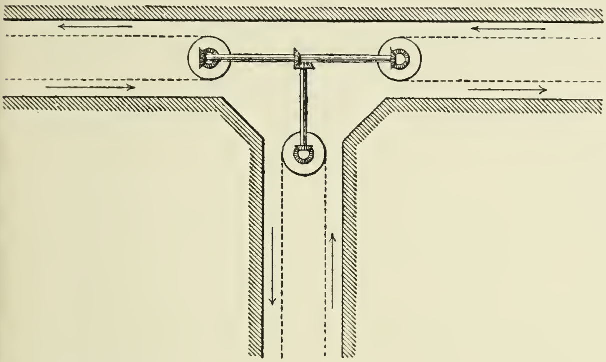


Fig. 277.—Endless Chain Haulage. Spur Gearing working a Branch from a Main Chain.

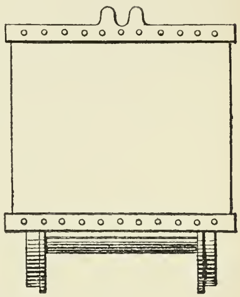


Fig. 278.—Iron Tub with Fork for Endless Chain Haulage.

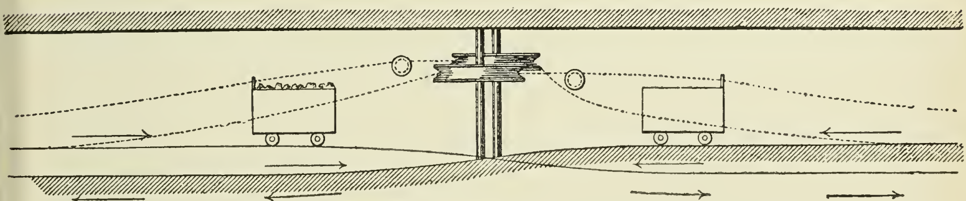


Fig. 279.—Endless Chain Haulage. Arrangement for Self-acting Curve.

Fig. 278, but where the coal stands high above the tub removable forks fitting into pockets in the tubs are used, and the length of the fork used is such as to enable the chain to stand sufficiently above the tub without touching the coal. A fork must be placed on both ends of the tub for this arrangement. In working round curves pulleys are placed to guide the chain, one for the full, and the other for the empty tubs. The road for the tubs, as they approach these pulleys, is made to rise, and just before reaching the pulley a fall commences. This causes the tub to leave the chain and pass round the curve under the pulley by its own momentum, and attaches itself again to the chain on the other side. Fig. 279 shows this.

Provision has been made to guard against the ill-effect of a broken chain. At the end of the plane, where a small guiding pulley is placed to direct the chain on to the driving-wheel, a movable catch may be placed, which keeps out of action whilst the chain is working properly, but if the chain breaks at that place the catch holds it. Again, claws are placed in the floor between the rails in both full and empty roads; if the chain breaks it falls down, and is held by these

claws. An automatic stop-block may be placed at intervals in the full road if the plane rises towards the shaft, and in the empty way if the plane falls towards the shaft. The tubs ascending press the stop-block down, and after the tub has passed over it rises again in position to catch and hold any tubs rushing back owing to a broken chain. This block would be applicable only under certain conditions of road.

Care should be taken that the tubs are placed on the chain at such intervals as to ensure keeping the chain from touching the ground. No rollers are required for the endless chain, a regular gradient is unnecessary, a heavy dip at one part of the plane may be succeeded by a rise.

A plane may have many changes in its rate and direction of inclination, and where this is so, the energy arising from the counterbalancing effect of the undulating road is not all lost. It is quite possible, where there is a continual load upon the heavy part of a plane in favour of the full tubs, for the plane to self-act, even although some portions of the plane may be flat or dip in favour of the empty tubs. The first cost of fitting the road is heavier than for the Tail rope, as the chain costs more than the ropes, and a double line of rails is necessary. There are, no doubt, circumstances in which each of the different methods will recommend themselves.

Signalling.—Until recently the method of signalling on engine planes was the same as on the self-acting inclined planes, by means of signal wire and hammers and levers.

If the engine was underground, a hammer was fixed in the engine-house. Attached to the hammer was a lever, from the end of which the wire was carried along the engine-plane and supported by iron hooks or staples driven at frequent intervals into the road-posts. If the engine was on the surface, the hammer was placed at a point near the bottom of the shaft convenient to the attendant who received the signals, and by means of another signalling arrangement communicated the signals he received to the engineman. At the terminus of the engine-plane and at any points between its ends from which it was desired to signal, levers were attached to this wire. By pulling the levers the hammer was raised and then (by releasing the lever) allowed to fall on to a flat piece of iron, making a distinct signalling sound.

This method has now, for the most part, given way to the electric signal. In the best form of this method, two wires are carried along the engine-plane throughout its course. The wires are about 6 inches apart, and are supported parallel to each other by insulators fixed to the road-posts or to the sides at intervals of about 20 yards; but this varies according to circumstances.

In the engine-house at the pit bottom, or wherever it is desired to receive the signal, an electric bell is fixed and a battery sufficiently powerful to keep the apparatus well supplied with an electric current. Having a return wire, signals may be given from one end to the other, or from any intermediate point, but can only be received at the electric bell. Through any portions of the plane which are subject to falling water, insulated wire must be used.

At any point on the plane, a signal may be given instantaneously by the "run-rider." He has merely to bring the two wires together and rub them with his fingers, or connect the two wires by tapping them with a short iron rod. Contact is at once formed and the bell rings. It is as easy to give a signal at a long as at a short distance from the engine, and less effort is required to ring the bell than in the old wire and hammer system. The first cost for the wire is also less, as a light wire answers the purpose, while in cost of maintenance it compares favourably with the old system. Besides these advantages it is impossible to

calculate the value of the convenience in signalling instantaneously from any point.

For convenience in repairing the road timbers, the wires should not be in one piece, but in short lengths of, say, 50 yards. The lengths are joined for ordinary working occasions, but may be quickly disconnected at any point of the engine-plane at night or whenever it may be necessary to renew timber in that part of the road.

A few questions and answers, bearing upon the subject of this chapter, will now be given, showing how to find the size of engines necessary to work engine-planes, &c.

Question 50.—What sized hauling engines would be required to haul 100 tons per hour by direct haulage up an incline 1,000 yards long rising 1 in 6, steam pressure being (in the boilers) 50 lbs. per square inch?

Here assume that the average speed is six miles an hour and the drum 5 feet in diameter, and that the engines are to be a pair working on the first motion. Assume that the engines have a 30-inch stroke, and if this works out disproportionately to the size of the cylinders it can be adjusted afterwards. Six miles $= 1{,}760 \times 3 \times 6 = 31{,}680$ feet. $1{,}000$ yards $= 3{,}000$ feet. To find the time occupied in making the journey one way, as $31{,}680 : 3{,}000 :: 60$ min. $\frac{3{,}000 \times 60}{31{,}680} = 5{\cdot}6$ say 6 minutes, as the time occupied by the train in travelling one way $= 12$ minutes and say 4 minutes interval $= 16$ minutes for each journey $= \frac{60}{16}$ or $3\frac{3}{4}$ trains per hour $\frac{100 \text{ tons}}{3{\cdot}75} = 26\frac{2}{3}$ tons, or say 27 tons per train. Suppose each tub to carry 10 cwt. this means 54 tubs, and if each tub weighs 4 cwt. there are 27 tons of coal and 10 tons 16 cwt. or say 11 tons of tubs $= 38$ tons as the gross load. But the inclination is 1 in 6, therefore $\frac{38}{6} = 6\frac{1}{3}$ tons as the net load. To consider its weight, assume a steel rope weighing 7 lbs. per yard is used; $1{,}000 \times 7 = 7{,}000$ lbs. as the weight of the rope, but the net load on an incline of 1 in 6 would be $\frac{7{,}000}{6} = 1{,}167$ lbs. and the net load exclusive of friction becomes $6\frac{1}{3}$ tons $= 14{,}187$ lbs. representing the tubs and coal $+ 1{,}167$ lbs. representing the rope $= 15{,}354$ lbs. acting at the circumference of a drum whose circumference is $15{\cdot}7$ feet. Add to this the friction. Experiments made to fix the co-efficient of friction for tubs at different times have given different results, varying from $\frac{1}{88}$th to $\frac{1}{28}$th of the gross load. Considering the friction of the rope on the rollers besides the wheels of the tubs, it will perhaps be prudent to adopt the highest co-efficient of friction, viz. $\frac{1}{28}$th of the gross load, and by adopting this it will be taking a proportion to cover friction of the rollers. The rope is 7,000 lbs., the tubs 11 tons or 24,640 lbs., the coal 27 tons or 60,480 lbs. $= 7{,}000 + 24{,}640 + 60{,}480 = 92{,}120$ lbs. total gross load: $\frac{92{,}120}{28} = 3{,}290$, the allowance for friction, which added to $15{,}354 = 18{,}644$ lbs., the actual load upon a circumference of $15{\cdot}7$ feet. $18{,}644 \times 15{\cdot}7 = 292{,}710$ the moment of load. The power is the pressure upon the piston, and its leverage is the double stroke of the piston 5 feet. Assuming $\frac{2}{3}$rds of the boiler pressure of 50 lbs. to be effective $= 33$ lbs. effective pressure. $\frac{292{,}710}{5 \times 33} = 1{,}774$ which gives theoretically the required piston area in square inches. To this add $\frac{1}{2}$ for general resistance and surplus power,

making the required piston area 2,661, or say 2,670 square inches for one cylinder and $\frac{2,670}{2} = 1,335$ square inches for each cylinder of a pair. $\sqrt{\frac{1,335}{\cdot 7854}} = 41\cdot 22$ as the diameter of the piston, so that a pair of engines will be required on the first motion with $41\frac{1}{4}$-inch cylinders and 30-inch stroke working a 5-foot diameter drum. But the cylinders and stroke are not proportioned to one another, and to find another proportion in which the area of cylinders × stroke will give the same power, proceed as follows:—Take the area of the cylinder at 1,335, and multiply this by the assumed stroke of 30 inches; $1,335 \times 30 = 40,050$. Now let the proportion of the stroke in the size, we shall find, be twice the diameter of piston.

Let x = the diameter in inches we wish to find.

Then $2x$ = the length of stroke in inches we wish to find.

Therefore $x^2 \times \cdot 7854 \times 2x = 40,050$ in order that the power may be equal to that of the size first ascertained.

$$x^2 \times 2x = \frac{40,050}{\cdot 7854}$$

$$2x^3 = \frac{40,050}{\cdot 7854}$$

$$x^3 = \frac{20,025}{\cdot 7854}$$

$x = 29\cdot 45$ or, say, 30 inches, as the diameter of the piston, and $30 \times 2 = 60 = 5$ feet as the length of stroke. To find the piston speed, 6 minutes is the time occupied by the train in travelling 3,000 feet, therefore the speed of the train on the average is $\frac{3,000}{6} = 500$ feet per minute. The drum has a circumference of $15\cdot 7$ feet, therefore $\frac{500}{15\cdot 7} = 31\frac{3}{4}$ revolutions per minute, the piston travels 10 feet for one revolution, therefore $31\frac{3}{4} \times 10 = 317\cdot 5$ feet per minute of piston speed, which is under a fair allowable speed. Now to look at the strength of the rope taken, viz., 7 lbs. per yard. The net load on the rope is 15,354 lbs. or $6\cdot 85$ tons. By the rule already given to find the circumference of a steel rope, whose working load is $6\cdot 85$ tons, $C = \sqrt{2\cdot 4 \times 6\cdot 85}$ = a little over 4 inches, and the weight of a 4-inch circumference steel rope is about 7 lbs. per yard.

> *Question* 51. A pair of hauling engines, 24-inch cylinders and 4-foot stroke, with a boiler pressure of 45 lbs. per square inch, and working on the first motion, by direct haulage, a plane 2,000 yards long, dipping from the shaft 1 in 9. What quantity of coal can be dealt with by such an engine, and what size drum would you use?

Assuming the maximum piston speed of 400 feet per minute, and that the trains run at an average rate of 8 miles an hour on a single line of rails, and that $\frac{2}{3}$ of the boiler pressure is effective, the power on the pistons would be $24^2 \times \cdot 7854 \times 30$ (the effective steam pressure) $\times 2$ (for the two cylinders) $= 27,143$, and deducting $\frac{1}{3}$ for frictional allowances $= 27,143 - 9,048 = 18,095$, travelling at 400 feet per minute. The tubs have to travel 8 miles an hour $= \frac{1,760 \times 3 \times 8}{60} =$ 704 feet per minute. While the piston travels $4 \times 2 = 8$ feet the crank travels $4 \times 3\cdot 14159 = 12\cdot 566$, say $12\frac{1}{2}$ feet, and while the circumference of the drum travels 704 feet, the piston travels 400 feet, and the crank travels $\frac{400}{8} \times 12\cdot 566$

$= 628$ feet. Therefore, as $628 : 704 :: 12{\cdot}566 : 14{\cdot}08$ circumference of the drum $= \frac{14{\cdot}08}{3{\cdot}14159} = 4{\cdot}48$ or $4\frac{1}{2}$ feet as the diameter. The load $\times$ $14{\cdot}08$ must equal the power. $\frac{18{,}095 \times 8}{14} = 10{,}340$ lbs., the load with which these engines are capable of dealing. To proportion this load so as to allow for weight of coals, weight of tubs, weight of rope and friction, proceed thus:—The steel rope will probably weigh about 5 lbs. per yard; $2{,}000 \times 5 = 10{,}000$ lbs., and this divided by the inclination $9 = 1{,}111$ lbs., which, deducted from the load, 10,340 lbs., leaves a balance of 9,229 lbs. This $\times$ 9, the inclination, $= 83{,}061$. Next allow $\frac{1}{28}$ of the gross load, viz., $83{,}061 + 10{,}000$ lbs. the rope $= 93{,}061$ lbs. for friction, $\frac{93{,}061}{28} = 3{,}324$ lbs. Deducting this from the balance of $9{,}229 = 5{,}905$. Multiply this by the inclination $9 = 53{,}145$. The tubs when empty will weigh from $\frac{1}{2}$ to $\frac{1}{3}$ of the load they carry, say $\frac{1}{3}$, then $\frac{53{,}145}{4} = 13{,}286$ lbs. as the weight of the tubs, and $53{,}145 - 13{,}286 = 39{,}859$ lbs. as the weight of coal. The speed of the rope is 704 feet per minute, and the distance being 2,000 yards $= 6{,}000$ feet, $\frac{6{,}000}{704} = 8\frac{1}{2}$ minutes each single journey will occupy, and $8\frac{1}{2} \times 2 = 17$ minutes each double journey, and allowing intervals amounting to 8 minutes, that means $\frac{60}{17 + 8} = 2{\cdot}4$ journeys per hour. The load of coal is 39,859 lbs. $\times\ 2{\cdot}4 = 95{,}661$ lbs. $\frac{95{,}661}{2{,}240} = 42{\cdot}7$ tons per hour. Showing that, with a pair of engines, having 24-inch cylinders, 4-foot stroke, running 400 feet per minute, and drum $4\frac{1}{2}$ feet in diameter, with a boiler pressure of 45 lbs. per square inch, 42·7 tons per hour could be dealt with from a distance of 2,000 yards, the inclination being 1 in 9, but as $4\frac{1}{2}$ feet is rather small, it would be better to use a 6-foot drum.

Question 52.—What size and description of hauling engine would you erect to haul 370 tons of coal per day of $8\frac{1}{2}$ hours by the endless chain, up a plane 1,250 yards long, the average inclination of which is 1 in 27, being a rise for the full tubs, and tubs holding 6 cwt. of coal being used?

Supposing the tubs to be placed at intervals of 15 yards apart, $\frac{1{,}250}{15} = 83$ full and 83 empty tubs on the road. The weight of coal would be $83 \times 6 = 498$ cwt. $= 24$ tons 18 cwt., and as there are the same number of tubs on each line of rails they will balance each other. The load on the engine will, therefore, be 24 tons 18 cwt., and the friction of the tubs and chain and gearing.

On an inclination of 1 in 27, the actual work done by the hauling engine $= \frac{498}{27}$ = say 18 cwt. The friction of the tubs, assuming they weigh 3 cwt. each, and that the co-efficient of friction is $\frac{1}{28}$, will be $\frac{83 \times 2 \times 3}{28} = 18$ cwt. There would be $1{,}250 \times 2 = 2{,}500$ yards of iron chain, say of $\frac{5}{8}$ inch diameter, weighing 11 lbs. per yard = about 246 cwt. and $\frac{246}{28}$ = nearly 9 cwt. The friction for the coal is $\frac{498}{28} = 18$ cwt. This gives a total load upon the chain of 18 cwt. coal + 18 cwt. friction of coal + 18 cwt. friction of tubs + 9 cwt. friction of chain = 63 cwt., besides the resistance from the driving pulleys round which the chain has to

pass. As these cannot well be calculated, allow 2 cwt., making 65 cwt. as the total load.

Now to arrive at the speed at which the chain must be worked. It is desired to draw 370 tons in $8\frac{1}{2}$ hours to the shaft $= \frac{370 \times 2,240}{8\frac{1}{2} \times 60} = 1,625$ lbs. per minute. 1 tub holds 6 cwt. $= 672$ lbs. and $\frac{1,625}{672} = 2 \cdot 4$ tubs per minute, say $2\frac{1}{2}$, as the rate of delivery from the chain to the shaft, and as they are placed 15 yards apart the speed of the chain must be $15 \times 2\frac{1}{2} = 37\frac{1}{2}$ yards, or say 113 feet per minute; $113 \times 60 = 6,780$ feet per hour, equivalent to $\frac{6,780}{5,280} = 1 \cdot 3$ mile an hour nearly. Now to fix on the size of engine. Assume that the driving-wheel is 3 feet in diameter, and that the stroke of the engine is 2 feet, and arrive at the proportion of gearing as follows; the speed of chain is 113 feet per minute; the driving-wheel has a circumference of $3 \times 3 \cdot 1416 = 9 \cdot 4248$. $\frac{113}{9 \cdot 4248} = 12$ revolutions per minute. The piston speed for an engine working continuously like this should not exceed 250 feet per minute, but take it at 200 feet per minute. With a stroke of 2 feet this would mean $\frac{200}{4} = 50$ revolutions per minute, so that the proportion of gearing would be as 50 is to 12, or about 4 to 1. The work done would be 65 cwt., at the rate of $1 \cdot 3$ mile an hour. $\frac{65 \times 112 \times 1 \cdot 3 \times 5,280}{60 \times 33,000} = 25$ horse-power, and assuming the engine yielded 50 per cent. of useful effect, the indicated horse-power would be 50 or 25 for each engine. This would be equal, supposing the effective steam pressure to be 30 lbs. to $\frac{25 \times 33,000}{30 \times 200} = 137 \cdot 5$, and $\sqrt{\frac{137 \cdot 5}{\cdot 7854}}$ $= 13 \cdot 23$ as the diameter in inches of the cylinders, and 2 feet as the length of stroke.

Question 53. What size hauling engines would you place underground to work an incline by tail rope whose rates of dip from the shaft are as follow:—For the first 200 yards, the dip is 1 in 28, for the next 400 yards it is 1 in 30, and for the next 500 yards which is the end of the plane it is 1 in 31. The coal to be brought out to be 1,000 tons in 8 hours.

	200 yards	1 in 28	$= \frac{200}{28} =$	$7\frac{1}{4}$
	400 ,,	1 in 30	$= \frac{400}{30} =$	$13\frac{1}{3}$
	500 ,,	1 in 31	$= \frac{500}{31} =$	$16\frac{1}{3}$
Total	1,100			37 and $\frac{1,100}{37} = 30$;

making the average gradient, therefore, 1 in 30.

Assume that the average speed is 8 miles an hour, and that the engines are to be a pair with 6-foot drums. Assume also that the engines have a 4-foot stroke, and that the gearing is 1 to 1. 8 miles $= 1,760 \times 3 \times 8 = 42,240$ feet. 1,100 yards $= 3,300$ feet. To find the time occupied in making the journey one way; as 42,240 : 3,300 : : 60 minutes : $4 \cdot 7$ say 5 minutes as the time occupied by the train in travelling one way $=$ 10 minutes, and say 5 minutes interval $=$ 15 minutes for each trip $= \frac{60}{15} = 4$ trains per hour; $\frac{1,000}{8 \times 4} = 31\frac{1}{4}$ tons per train.

Suppose each tub to hold 10 cwt., this means 63 tubs, and if each tub weighs 4 cwt. it means $31\frac{1}{4}$ tons of coal, and $63 \times 4 = 252$ cwts. or 12 tons 12 cwts. of tubs = say 44 tons as the gross load. But the average inclination being 1 in 30, $\frac{44}{30} = 1\frac{1}{2}$ tons nearly as the net load. The ropes to some extent balance each other, but as it is usual to make the main rope stronger than the tail rope take this into account. Supposing a $2\frac{1}{4}$ lb. per yard steel rope to be used for the main and a $1\frac{1}{2}$ lb. per yard for the tail rope, then $2\frac{1}{4} - 1\frac{1}{2} = \frac{3}{4} \times 1{,}100 = 825$ lbs. as the weight of the rope, the net load of which would be $\frac{825}{30} = 28$ lbs. nearly. The net load exclusive of friction is $1\frac{1}{2}$ tons = 3,360 lbs. representing the tubs and coal + 28 lbs. representing the rope = 3,388 lbs. acting at the circumference of a drum whose circumference is $6 \times 3{\cdot}1416 = 18{\cdot}849$ feet. But add to this the friction. The ropes are $1{,}100 \times 2\frac{1}{4} + 1{,}100 \times 1\frac{1}{2} = 1{,}100 \times 3\frac{3}{4} = 4{,}125$ lbs., the tubs 252 cwts. or 28,224 lbs., the coal $31\frac{1}{4}$ tons or 70,000 lbs. $4{,}125 + 28{,}224 + 70{,}000 = 102{,}349$ lbs. total gross load. $\frac{102{,}349}{28} = 3{,}655$ lbs., the allowance for friction which added to $3{,}388 = 7{,}043$ lbs. the actual load upon a circumference of 18·849. $7{,}043 \times 18{\cdot}849 = 132{,}754$ the moment of load. A 4-foot stroke and an effective steam pressure of 30 lbs. $= \frac{132{,}754}{4 \times 2 \times 30} = 553$, the theoretical required piston area in square inches. Add $\frac{1}{2}$ for general resistance, making the required piston area 830 square inches for one cylinder. $\frac{830}{2} = 415$ square inches for each cylinder of a pair. $\sqrt{\frac{415}{{\cdot}7854}} = 22{\cdot}98$, or say 23 inches as the size of the pair of engines required, with a 4-foot stroke which is pretty well in proportion and 6-foot drums. Now to test the piston speed. The train travels 3,300 feet in 5 minutes $= \frac{3{,}300}{5} = 660$ feet per minute. The drums have a circumference of 18·849 feet, therefore $\frac{660}{18{\cdot}849} = 35$ revolutions per minute, and $35 \times 8 = 280$ feet per minute of piston speed, which is well under a fair allowable speed. The net load on the rope is 3,388 lbs. or 1·6 ton $\sqrt{2{\cdot}4 \times 1{\cdot}6} = 2$ inches nearly circumference, and the weight of a 2-inch circumference steel wire-rope is $4\frac{1}{4}$ lbs. per fathom or $2\frac{1}{8}$ lbs. per yard, so that the rope chosen weighing $2\frac{1}{4}$ lbs. per yard is quite strong enough for the purpose.

Question 54.—A train of 10 tubs, ascend an incline, each tub (with coal) weighs 1 ton with a rise of $4\frac{1}{2}$ inches per yard, what is the power required and the strain on the rope?

Assume that the friction of the tubs is $\frac{1}{28}$th of their weight. A rise of $4\frac{1}{2}$ inches per yard $= \frac{36}{4\frac{1}{2}} = 1$ in 8, 10 tubs $\times 2{,}240 = 22{,}400$. $\frac{22{,}400}{28} = 800$ lbs. necessary to overcome friction, and $\frac{22{,}400}{8} = 2{,}800$ lbs. necessary to overcome gravity, which would be the power without considering friction; the amount of strain on the rope would be therefore $800 + 2{,}800 = 3{,}600$ lbs. = 1 ton 12 cwts. 0 qr. 16 lbs. It often happens that $\frac{1}{70}$th of the weight is taken for the friction, if that were adopted it would mean $\frac{22{,}400}{70} = 320$ lbs. for friction. 2,800 lbs. for gravity as before = 3,120 lbs. total = 1 ton 7 cwts. 3 qrs. 12 lbs., but the former allowance is preferable as being safer.

Question 55. Are hauling engines sometimes worked with compressed air as a motive power?

Yes, and it has great advantages over steam under certain conditions, as the latter is not a convenient motive power to convey far into a mine. An engine, whether for hauling, working rock-drills or coal-cutting machinery, worked by compressed air can be placed at any point in the workings, near the shaft or far away from it. It has also been successfully applied as a motive power to supply locomotives running underground, in which case the engine carries compressed air in a reservoir. The exhaust although hardly appreciable in well ventilated pits is of some use in improving the ventilation in the workings, and the pipes along which the compressed air is conveyed are cool and last long.

The disadvantages in using compressed air are many. First, it requires extensive plant on the surface, a steam-engine being necessary in the first instance to produce the compressed air. A very low proportion of the work done in the steam engines is given by the engines using the compressed air, not more than from 25 to 30 per cent., so that 2 or 3 times as much fuel is consumed as would be necessary if steam were used direct. The reasons for this low useful effect are, first, the fact of having a second engine to employ with its friction to overcome, and loss of heat in compressing the air, which passes through the compressing cylinders; secondly, the leakage of the valves and pistons, and the friction of the air in being carried from the receiver along the pipes; thirdly, little expansion is obtained out of the compressed air; and fourthly, during compression the temperature of the air is increased, and therefore its bulk; on leaving the cylinder its bulk is reduced again, so that the work of compression is performed on a larger bulk of air than work is obtained from.

The compressed air on being liberated absorbs the heat from the surrounding air, causing a great degree of cold, and, unless dry air be used, ice is formed in the cylinder and the exhaust pipe. The means of producing the compressed air and applying it are as follow:—A horizontal steam-engine is so placed that the continuation of its piston-rod through the back cylinder cover forms the piston-rod for the cylinder of the compresser, the piston of the compresser being rather larger than the piston of the steam cylinder. By an arrangement of valves in the air cylinder (which is usually surrounded by water to keep it cool; the water absorbing the heat generated during compression and conducting it through the metal), the air enters the cylinder behind the piston, and is forced out of the cylinder in front of the piston through pipes into a receiver of large dimensions loaded to the required pressure, from which pipes convey it down the pit and along the workings to the engine to be supplied with compressed air.

There are circumstances in which no other motive force can be so well applied, but on economical grounds, wherever practicable, steam should be employed direct.

Question 56.—What are compound hauling engines?

Compound engines have two or more cylinders, and the same steam works in all the cylinders successively and expansively. Usually only two cylinders are used, one having the smaller diameter being the high-pressure cylinder into which the steam as it leaves the boiler passes, and after completing the stroke, then into the other, which is the larger or low-pressure cylinder. The steam is used expansively in both cylinders, and leaves the low-pressure cylinder only a little above the atmospheric pressure. A receiver is placed between the high and low-pressure cylinders, to equalise the back pressure on the high-pressure piston and the initial pressure on the low-pressure piston. The low-pressure cylinder may have a valve applied to it so that high-pressure steam can be admitted to it at the first few revolutions when the engines have the heaviest lift. Com-

pound engines have been applied more to work pumps than for hauling and winding.

Question 57.—It is intended to erect a pair of coupled engines, working direct without gearing to haul 8 full coal tubs each weighing 11 cwt. (load and tub) up an inclined plane 560 yards long and rising 1 in 7. The desired rate of speed is 10 miles an hour. What size and stroke should the engines be and how many revolutions per minute? The drum of the engine is 3 feet diameter, and the rope not allowed to overlap itself on it. The boiler pressure of steam is 35 lbs.

A rope of steel wire having a circumference of $1\frac{1}{2}$ inches would weigh 1 lb. per yard; the total weight would be 560 lbs. The whole weight on the engine due to gravitation would be 8 tubs @ 11 cwt. $= 8 \times 11 \times 112 = 9{,}856$ lbs. $+ 560$ lbs. $= 10{,}416$ and $\frac{10{,}416}{7} = 1{,}488$ lbs.; that due to friction inclusive of rollers, &c. would be $\frac{10{,}416}{28} = 372$ lbs. Total load $= 1{,}488 + 372 = 1{,}860$ lbs. The diameter of drum being 3 feet the circumference is 9·4248 feet. $1{,}860 \times 9{\cdot}4248 = 17{,}529$ the moment of load. An 18-inch stroke and a boiler pressure of 35 lbs. $= \frac{35 \times 2}{3} =$ say 23 lbs. effective pressure; $\frac{17{,}529}{1\frac{1}{2} \times 2 \times 23} = 254$ the theoretical piston area, to which add $\frac{1}{2} = 254 + 127 = 381$ for one cylinder and $\frac{381}{2}$ say 191 square inches for each of a pair $\sqrt{\frac{191}{{\cdot}7854}} = 15{\cdot}59$ as the diameter of a pair, say $15\frac{1}{2}$ inches. The rate at which the trams are hauled is 10 miles an hour: $\therefore \frac{10 \times 1{,}760 \times 3}{60 \times 9{\cdot}4248}$ $= 93{\cdot}37$ say $93\frac{1}{3}$ revolutions of a drum per minute, and the drum makes one revolution for three feet of piston travel $= 93\frac{1}{3} \times 3 = 280$ feet as the piston speed per minute—quite an allowable speed. To find the horse-power of these engines

$$\frac{15\frac{1}{2}^2 \times {\cdot}7854 \times 2 \times 280 \times 23}{33{,}000} = 74 \text{ horse-power.}$$

If as stated the rope is not to overlap itself on the drum which in hauling up a plane 560 yards long makes $\frac{560 \times 3}{9{\cdot}4248} = 178$ revolutions, and the rope is about $\frac{1}{2}$-inch diameter, therefore $178 \times \frac{1}{2}'' = 89$ inches or 7 ft. 5 in., so that the drum would have to be 7 feet 6 inches in length, if 3 feet in diameter, which is rather an unusually small size.

Question 58.—The weight of the tubs, coal, rope, &c., which is pulled up a slant whose angle is 26 degrees, amounts to 70 cwt. What is the working load of the rope, friction $\frac{1}{70}$?

As there are 57·3° in an arc whose length = radius, approximately for this purpose the value of a rise of 26° in inches per yard may be expressed by taking a circle whose radius is one yard or 36 inches. Multiply this radius by 26° (the number of degrees) and divide by 57·3° and get approximately the rise per yard, thus $\frac{36 \times 26}{57{\cdot}3} = 16$ inches rise per yard $= \frac{36}{16} = 1$ in 2·25. Therefore the force of gravitation on a weight of 70 cwt. is $\frac{70}{2{\cdot}25} = 31{\cdot}1$ cwt.

The force due to friction would be $\frac{70}{70} = 1$ cwt., hence the working load of the rope would be $31{\cdot}1 + 1 = 32{\cdot}1$ cwt. or $32\frac{1}{9}$ cwt.

Question 59.—At what gradient would the full tubs hold the empties in suspension, the set to consist of 8 full tubs weighing 11 cwt. each and 8 empties weighing 3 cwt. each, friction $\frac{1}{70}$th?

Equilibrium will ensue when the sum of the friction of the two loads is equal to the difference of their gravity on the incline. Supposing in the question asked that the weight of each load respectively includes the weight and friction of rope, friction of rollers, &c., connected with it; then—

Let 1 in x denote the gradient;

$$\text{then } \frac{11 \times 8}{x} - \frac{3 \times 8}{x} = \frac{(11 \times 8) + (3 \times 8)}{70};$$

$$\therefore \frac{88}{x} - \frac{24}{x} = \frac{112}{70}$$

$$\text{and } \frac{64}{x} = 1{\cdot}6$$

$$64 = 1{\cdot}6\,x$$

$$x = \frac{64}{1{\cdot}6} = 40.$$

Therefore the gradient would be 1 in 40. Put as a formula for the above rule, $(F - E)\,R = (F + E)\,G$, where F stands for the full loads, E for the empty ones. R the denominator of the fraction of the friction, the numerator of which is always 1, G the denominator of the fraction of the gradient, the numerator of which is always 1.

Question 60.—What ought to be the gradient of a horse road when the loaded train consists of six tubs 18 cwt. each, and six empties of $4\frac{1}{2}$ cwt. each, friction $\frac{1}{70}$th, so that the resistance may be equal both ways?

In this case resistance is equal when the friction of the full load, less its gravitation, is equal to the friction of the empty load, plus its gravitation.

Let 1 in x denote the gradient;

$$\text{then } \frac{108}{70} - \frac{108}{x} = \frac{27}{70} + \frac{27}{x}$$

$$\therefore \frac{27}{x} + \frac{108}{x} = \frac{108}{70} - \frac{27}{70}$$

$$\frac{135}{x} = \frac{81}{70};$$

$$x = 116\tfrac{2}{3},$$

the gradient therefore is 1 in $116\frac{2}{3}$. Express this rule by a formula, using the same expressions as in the last example, as follows—

$$\frac{F}{R} - \frac{F}{G} = \frac{E}{R} + \frac{E}{G} \therefore (F + E)\,R = (F - E)\,G.$$

Question 61.—What are the usual methods of determining the size of the high and low-pressure cylinders of compound engines, and how is the horse-power of such engines calculated?

It is necessary, in the first place, to determine the rate of expansion in compound engines, then if A = area of low-pressure cylinder, a = area of high-pressure cylinder, E = rate of expansion $= \frac{A\,L}{a\,l}$, L = length of stroke in feet.

& l = distance travelled by piston before steam is cut off in the high-pressure cylinder. The best proportion for the two cylinders is when $a = A \div \sqrt{E}$, so if the steam is to be expanded 4 times $a = \cdot 5$ A, and, as the formula assumes the steam being also cut off at ·5 of the stroke in the small cylinder, then the initial volume × 4 = the final volume $a \times \cdot 5 \text{ L} \times 4 = \text{A} \times \text{L}$. To find the horse-power, each cylinder should be indicated to find the mean effective pressure in each, then treat each as a separate engine and add the results together.

Question 62.—What is the horse-power of a pair of hauling-engines, the diameter of cylinders being 16 inches, stroke 30 inches, number of strokes per minute 25, pressure of steam 35 lbs.; the engine is geared as follows. The crank is connected to a shaft containing a pinion with 15 teeth which drives a spur-wheel having 70 teeth. On the same shaft containing this spur-wheel is a pinion with 20 teeth which drives a spur-wheel on the drum shaft with 80 teeth.

The effective horse-power of an engine is only slightly reduced owing to the additional friction which has to be overcome. Of course a greater weight would be lifted but for the gearing, at a sacrifice of speed; for instance, whilst the crank-shaft made one revolution the 70-toothed spur-wheel would only make $\frac{15}{70}$ths of a revolution, so that whilst the 70-toothed spur-wheel makes one revolution the crank would make $\frac{70}{15} = 4\frac{2}{3}$ revolutions, and whilst the pinion on the spur-wheel shaft makes one revolution the spur-wheel on the drum shaft only makes $\frac{20}{80}$ or $\frac{1}{4}$th of a revolution. Therefore whilst the drum revolves once the crank revolves $4\frac{2}{3} \times 4 = 18\frac{2}{3}$ times.

The horse-power of the engines would be

$$\frac{16^2 \times \cdot 7854 \times 2 \times 2\frac{1}{2} \times 2 \times 25 \times 35}{33{,}000} = 53 \cdot 312 \text{ H.-P.}$$

Question 63.—What sized hauling-engines or horse-power would be required to draw 120 tons per hour up an incline 1,500 yards long, gradient 1 in 8, at a speed of 4 miles per hour? Could the engines be geared to the hauling drum by spur-wheels in the proportion of 5 to 1?

This is a large quantity to bring up the incline stated, and if direct haulage be adopted, necessitating a double line of rails throughout, or the laying of the rails may be by a three-plate way above meetings and a single one below after the manner of a self-acting incline; but this would be possible only if there are no branch roads and the incline is straight throughout its course. A pair of engines would of course be necessary, and assume the drums to be 6 feet. A speed of 4 miles an hour = 1,760 × 3 × 4 = 21,120 feet. Length of plane 1,500 × 3 = 4,500 feet, $\frac{4{,}500 \times 60}{21{,}120}$ = 13 minutes nearly, as the time occupied by the trains travelling, and as no time must be wasted in order to get up this quantity, allow an interval of 2 minutes to change the trains at both ends, &c., and one train would arrive at the shaft every 15 minutes, ∴ $\frac{60}{15}$ = 4 trains per hour, and $\frac{120}{4}$ = 30 tons to be sent per train. Suppose each tub to carry 10 cwt., then 60 tubs are required, and say each tub weighs 4 cwt., there are 30 tons of coal, but as the two trains of tubs will balance each other, they need not be considered, except for friction. Then a steel rope weighing about 8 lbs. per yard would be necessary, 1,500 × 8 = 12,000 lbs. 30 tons = 67,200 lbs., which, added to 12,000 = 79,200 and $\frac{79{,}200}{8}$ = 9,900 lbs. as the load due to gravity. For the friction we have 120 tubs at 4 cwt. each = 480 cwt. = 53,760 lbs., and

$\frac{53{,}760 + 79{,}200}{28} = 4{,}749$ lbs. the allowance for friction. $9{,}900 + 4{,}749 = 14{,}649$ lbs. as the actual load upon a circumference of 18·849. $14{,}649 \times 18{\cdot}849 = 276{,}119$ the moment of load. Assuming a 5-foot stroke and 30 lbs. effective steam pressure $\frac{276{,}119}{10 \times 30} = 920{\cdot}4$ theoretical piston area, to which add $\frac{1}{2}$, $920{\cdot}4 + 460{\cdot}2 =$ say, $1{,}381 = 691$ for one cylinder and $\sqrt{\frac{691}{{\cdot}7854}} = 29{\cdot}66$, or say 30 inch cylinders. The size of the engines is not affected by the gearing, this would only affect the piston speed maintained in doing the work. To consider the possibility of gearing the engines, the drums are to be 6 feet in diameter and have a circumference of 18·849 feet. The speed of the ropes is $\frac{4{,}500}{13} = 346$ feet per minute and therefore the drums revolve $\frac{346}{18{\cdot}849} = 18{\cdot}4$ times per minute. The piston speed must not exceed 400 feet per minute and as the stroke is 5 feet, $\frac{400}{5 \times 2} = 40$ revolutions of the engine. The proportion of gearing must therefore not exceed 18·4 to 40 or say 2 to 1, and it would be better not to use gearing at all with 6-foot drums, in which case the piston speed would be $5 \times 2 \times 18{\cdot}4 = 184$, thus allowing a margin for occasional quicker speed following delays through accident.

Question 64.—How do you proceed to calculate the friction of tubs?

By allowing the tubs to run down an incline with a regular gradient, taking the length of the incline and noting the time occupied by the tubs in traversing it. The gradient must, of course, be ascertained if not known, and the experiment may be tried on either full or empty tubs.

Resistance due to friction $= \frac{H}{D} - \frac{D}{T^2 \times 16\frac{1}{12}}$ where H = height of plane in feet, D = length of plane in feet, T = time in seconds taken by tub to traverse the distance D.

Supposing a tub traversed a plane 150 feet long and having a fall between the two ends of 5·74 feet in 20 seconds, the resistance due to friction is found thus;—

$\frac{5{\cdot}74}{150} - \frac{150}{20^2 \times 16\frac{1}{12}} = {\cdot}01495$, so that if the loaded tub weighed 1,804 lbs., $1{,}804 \times {\cdot}01495 = 26{\cdot}97$ lbs. and $\frac{26{\cdot}97}{1{,}804} = \frac{1}{66{\cdot}9}$ say $\frac{1}{70}$th as the co-efficient of friction.

If an empty tub traversed the same plane in 23 seconds and the tub weighed 688 lbs., then $\frac{5{\cdot}74}{150} - \frac{150}{23^2 \times 16\frac{1}{12}} = {\cdot}02063$ and ${\cdot}02063 \times 688 = 14{\cdot}2$ lbs. and $\frac{14.2}{688} = \frac{1}{48{\cdot}45}$ say $\frac{1}{48}$th as the co-efficient of friction.

Another way of finding the co-efficient of friction is by placing the tub on a perfectly level piece of the road laid in the ordinary way, and attaching one end of a cord to the tub, the other with a weight at the end is passed over a pulley, and whatever weight is found sufficient to keep the tub in motion without accelerating its speed is taken as the amount of friction, and this weight divided by the weight of the tub operated on gives the co-efficient of friction.

Another method consists in starting a tub down a piece of road which becomes gradually flatter and observing where the tub comes to rest. The average gradient between the starting and resting points shows the ratio of the friction to

the weight. If a tub continues to run on $\frac{1}{2}$ an inch per yard dip or 1 in 72, the friction is under $\frac{1}{72}$ of its weight; on 1 inch to the yard or 1 in 36 the friction is under $\frac{1}{36}$th of its weight.

Question 65.—What gradient would be necessary for a self-acting incline whose length is 300 yards, six tubs being sent on either side, the empty tubs weighing 5 cwt. each, and 9 cwt. of coal being sent in each, a steel rope of $1\frac{1}{2}$-ins. circumference being used, the friction of the loads being taken at $\frac{1}{50}$th of the weight, and the friction of the rollers at $\frac{1}{25}$th of their weight.

Ascertain by the rule already given the gradient at which the full and the empty trains just balance each other, then it is evident that a slight increase in the gradient will be sufficient to give them motion.

The full train is $(9 + 5) \times 6 \times 112 = 9{,}408$ lbs. The empty train is $5 \times 6 \times 112 = 3{,}360$ lbs. A $1\frac{1}{2}$-inches circumference steel rope weighs nearly 1 lb. per yard. On 300 yards = 300 lbs. Rollers, say 30 @ 12 lbs. = 360 lbs. The friction then on the loads and tubs will be $\frac{9{,}408 + 3{,}360}{50} = 255{\cdot}3$ lbs., that on the rope and rollers will be $\frac{300 + 360}{25} = 26{\cdot}4$. $255{\cdot}3 + 26{\cdot}4 =$ say 282 lbs. The full load is 9,408 lbs. and the empty load 3,360 + the 300 lbs. of rope on it = 3,660. The difference in gravity therefore is $9{,}408 - 3{,}660 = 5{,}748$ lbs., and since equilibrium will ensue when the sum of the friction of the two loads is equal to the difference of their gravity, $5{,}748 \text{ lbs.} \times \frac{1}{G} = 282$ lbs. $\therefore \frac{1}{G} = \frac{282}{5{,}748} = \frac{1}{20{\cdot}4,}$ therefore the gradient would be 1 in 20·4, for the full and empty trains to balance each other, and it therefore should be 1 in 18 or 2 inches per yard to overcome the resistance of the drum and give motion to the trains. If the gradient is not quite uniform the heaviest part should be at the top.

Question 66.—An engine draws 10 tubs of coal up an incline 100 yards long whose gradient is 1 in 9, at an average speed of 5 miles an hour, what will the same engine draw on a level road of the same length? A steel-wire rope weighing 7 lbs. per fathom is used.

Suppose the loaded tubs to weigh 10 cwt. each, $10 \times 10 \times 112 = 11{,}200$ lbs. For the rope $100 \times 3\frac{1}{2} = 350$ lbs. $\frac{11{,}200 + 350}{9} = 1{,}284$ lbs. due to gravity. Take $\frac{1}{28}$th the gross load for friction, $\frac{11{,}200 + 350}{28} = 413$ lbs. due to friction. The load would be $1{,}284 + 413 = 1{,}697$ lbs. travelling 5 miles an hour, $\frac{1{,}697 \times 5 \times 5{,}280}{60 \times 33{,}000} = 22{\cdot}63$ horse-power. Of course the engine would require to have double this horse-power, but for the purpose of the comparison made, that need not be considered. To ascertain how many tubs an engine of the same size will draw along a level road 100 yards long at the rate of 5 miles an hour, the work of the engine per minute would be $22{\cdot}63 \times 33{,}000 = 746{,}790$ lbs., but a good deal of the work would be devoted to overcoming friction. A tail rope would be necessary on the level road, which would make double the amount of friction for rope. Per minute it would be

$\frac{700 \times 5 \times 5{,}280}{28 \times 60} = 11{,}000$. $746{,}790 - 11{,}000 = 735{,}790$ lbs. The work due to friction on each tub of coal per minute would be $\frac{1{,}120 \times 5 \times 5{,}280}{28 \times 60} = 17{,}600$, $\therefore \frac{735{,}790}{17{,}600}$ = nearly 42 tubs of coal the engine under these circumstances would take out, but if the co-efficient of friction be taken at $\frac{1}{70}$th of the gross load, as is frequently done, the difference between what would be done on an incline of 1 in 9 and a level road of equal length would be more marked.

Question 67.—What should be the diameter of the low-pressure cylinder of a compound hauling-engine, if that of the high-pressure cylinder is 18 inches, the initial pressure of the steam being 147 lbs. above that of the atmosphere and exhausting at 3 lbs. above the atmosphere, the length of stroke being 27 inches? At what point in the stroke would the steam be cut off?

Here the absolute initial pressure of the steam is $147 + 15 = 162$ lbs., and the pressure on leaving the low-pressure cylinder is $3 + 15 = 18$ lbs. The rate of expansion therefore is as $18 : 162$, or 9 times.

By the formula $a = A \div \sqrt{E}$, therefore $18^2 \times {\cdot}7854 = A \div \sqrt{9}$ $\therefore$ $254{\cdot}469 = \frac{A}{3}$ $\therefore$ $A = 254{\cdot}469 \times 3 = 763{\cdot}407$; and therefore the diameter of the low-pressure cylinder is $\sqrt{\frac{763{\cdot}407}{{\cdot}7854}} = 31{\cdot}17$ inches. The expansion being 9 times, the steam is cut off at $\sqrt{9} = \frac{1}{3}$rd of the stroke.

CHAPTER IX.

DRAINAGE.

Winding Water up Shafts—Lifting and Forcing Pumps—Making Pipe Joints Watertight—Balance Bobs—The Windbore—Clack-piece—Fish-piece—The Working Barrel—Action of the Pumps—Water Speed in Pipes—Construction and Method of securing Pumps—Preserving Pipes from the Action of Mineral Water—Pump Rods:—Their Material; Method of Joining; Steadying; Safety Catches—Attachment of Bucket to Spears—Hanging Clack and Bucket Doors—General Arrangement of Lifting and Forcing Sets of Pumps—Determination of Weight Necessary for Balance Bobs—Use and Action of the Air Vessel—Bunton and Plank Brattices to form compartment in Shaft for Pumps—Arrangement for a Sinking Set of Pumps—Sliding Suction for Sinking Set—Messrs. Thornewill and Warham's Details of Pump Work—The "Deane" Sinking Pumps—The Cornish Pumping Engine—The Cornish Double-beat Valve—Davey's Differential Valve Gear for Cornish Engine—Davey's Compound Differential Pumping Engine—Relative Advantages of placing Pumping Engines Above and Underground—Steam Pumps—The Compound Differential Engine as arranged underground—The Worthington Pumping Engine—Compressed Air for underground Pnmping Engines—Hydraulic Pumps—Moore's Hydraulic Mine Pump—Wire Rope Systems of Pumping—Electrical Pumping Plant at the Trafalgar Colliery—Syphons for Drainage of Underground Roadways—Memoranda—Powers of Engines for given work—The Pulsometer, its Action and Use—Pulsometer arrangement for Draining Underground Workings—Calculation of Contents of Water Barrels.

THE water which finds its way into the underground workings must be removed. In the case of an adit driven at a proper rise and having no workings to the dip, the water will run out without trouble; but in the case of a pit with workings far enough beneath the surface, the water is removed either by pumps placed in the shaft, or by tanks placed in the cage, to be used when the pit has done drawing coals for the day. Unless the quantity is very small indeed, it is found an advantage to have pumps, for with only 20 galls. per minute to be removed it would take more than 6 hours winding, lifting one ton at a time at the rate of 20 tons per hour, giving 3 minutes to fill, wind the cage, and empty. There are two kinds of pumps used—the *lifting* and the *forcing*. In the lifting pumps, a bucket works in the working barrel, the part of the pump below the bucket is called the "suction," and above it the lift. The suction should not exceed from 20 to 24 feet in height. The height of the lift, limited by the strength of the material and the weight of the spears, does not usually exceed 50 fathoms. Spears or pump-rods connect the bucket working in the barrel with the beam of the engine, and as they are inside the pipes conveying the water up the shaft, they reduce the area of these for the water, and so increase the friction. Lifting pumps are not suitable to great depths on account of the wear and tear to the leather rings forming the packing of the bucket, necessitating frequent change, and costing a considerable amount for repairs. In the forcing or plunger pumps the plunger pole, or ram, works through a stuffing box into a plunger case of bored cast-iron, and at every down stroke the water is forced upwards through an upper clack into the column of pipes above, and these pipes in the plunger pumps are quite clear for the ascent of the water.

The advantage of the forcing method is that there is less wear and tear, the hemp packing of the stuffing box is preferable to the leathers of the bucket, as giving less friction and being more durable. It is not necessary to remove the

ram itself to do the repairs, but in the lifting pumps the bucket must always be withdrawn from the working barrel when it is necessary to repair it. The spears of the plunger pumps are exposed to view in the shaft, and in their descent their weight is sufficient to force the water before them. In deep mines, where the large moving parts are heavier than the column of water raised, it is necessary to counterbalance the extra weight by balance bobs placed at the surface or at intervals in the pit, or both. The joints between the various lengths of pipes and that between the door and clack-piece are made tight by thin layers of some soft material, such as tarred flannel, which is wrapped round a ring of lead or wrought-iron, screw bolts and nuts being employed for tightening them at the flanges.

In both kinds of pumps the bottom piece is called the windbore, or suction piece, and has a number of holes in the bottom, covered by the water in the sump of the pit or cistern in which it may be placed, and these holes are made of such a size as to prevent pieces of wood or stone from entering the windbore with the water. As a further precaution the windbore is sometimes surrounded by a gauze cage. The next is the clack-piece, provided with a door, and contains the clack, which is a kind of valve resting in its seat. The clack may be taken out for repairs through the clack-door, and if there is any risk of this being at times impracticable, it is made with a bow on the top, so that a hook, called a fish-piece, may be attached to the end of the spears in place of the bucket and passed down the column and secured to the bow of the clack, which is thus lifted out of its seat and up the column of pumps. The fish-piece, shown at Fig. 280, is frequently used during sinking operations. When the fish-piece passes through the clack bow, the protruding pieces at the sides are forced in, and after it has gone further downwards they are again forced outwards by the springs shown on the drawing. On the fish-piece now being raised these protruding pieces project beyond the bow and lift it with them.

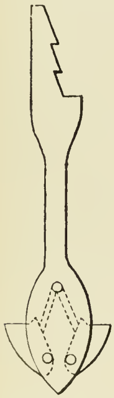


Fig. 280.—Fish-piece.

The next piece above the clack-piece is the working barrel, which, in the case of a lifting set, has the bucket working in it, and attached to the bucket are the spears extending upwards inside the column of pumps to the beam of the engine, or to a set-off or "apron" attached to the main spears working other sets of pumps in the same shaft. At the top of the working barrel is the bucket door-piece, by removing the door of which the bucket may be taken out for repairs. As the rods descend the bucket moves down the working barrel, the clack-valves fall and prevent the water from descending again to the windbore, and at the same time the bucket-valves open and the water, except that displaced by the bucket and rod, remains in the working barrel.

At the upstroke of the engine, the bucket-valves close, and the water which stood in the working barrel at the down stroke is lifted on top of the bucket up the pumps, whilst, owing to the pressure of the atmosphere on the water in the sump, the water follows the course of the bucket in its ascent, and fills the working barrel. If the holes of the windbore are not covered by a foot or two of water, air will pass through them. This is unavoidable during sinking operations, for the pump must keep the water down to the lowest point, and it therefore often works partly on air. In all permanent pumps, however, care must be taken in working the engine that this does not occur.

In the sketch of a lifting and forcing set of pumps shown at Fig. 281, the necessity of two clack-pieces, with their clacks and doors in the plunger set of pumps, is evident. As the ram descends the bottom clack closes, the water passing through the upper clack to the column of pipes above. As it ascends the

bottom clack opens, and the water from the cistern follows its course, the water in the column of pipes by its weight at the same time closing the upper valve. The diameter of pipes which form the rising main and the thickness of metal in the pipes depend upon the quantity of water to be raised, and the height it has to be lifted. These must be calculated. In order to reduce the shocks to which all pumps are liable the velocity of the water in the pipes should not exceed 240 feet per minute, and it will be better to limit it to 200 feet per minute. The pipes should be cast of a uniform thickness, and have brackets under the flanges, as well as a belt round the pipe at the socket end so as to better resist the strain in screwing up the joints. All the pipes should be faced, and have just sufficient spigot to keep the ring in position. They are usually made 9 feet long. To preserve the pipes from the action of the mineral water (if such is being raised), they are lined with a thin casing of wood. The pumps are kept steady by collars placed across from the buntons to the side of the shaft at each alternate pipe, so that these collars would be 18 feet apart. The pump rods or spears are usually made of Memel or pitch pine, square in section, and must be as sound and free from knots and faults as possible. They should be of uniform lengths, so that a spare rod will fit anywhere, and may be from 30 to 45 feet long. The lengths are put together by scarfed joints (Fig. 282), and secured by stout wrought-iron plates and bolts. Sometimes these plates are placed on two sides only, but often a plate is placed on each of the four sides. Where the plates are single there should be clinch-bolts a little above the other

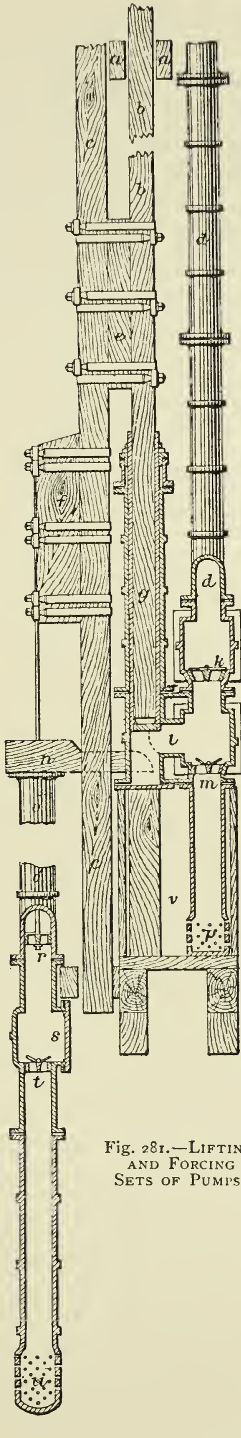


Fig. 281.—Lifting and Forcing Sets of Pumps.

Reference.

t, is the clack in its seat in the lifting set, and *s* is the clack door.

r, is the bucket working in the working barrel *o'*.

o, is the rising main of the lifting set and *u* the windbore.

n, is a wooden trough by means of which the water is delivered into the cistern *v*, from which the forcing set takes its water.

f, is the set-off and iron straps from the main rods *c*.

In the lifting set that part of the pipe between the bottom of the working barrel and the top of the clack piece is usually slightly reduced in size, and this allows of a drop valve with bow being dropped down into position after the bucket has been drawn up through the rising main, if it should ever become necessary.

g, is the ram of the forcing set, and *e* its set-off and iron straps by means of which it is secured to the main rods *c*.

b, are spears working through guides *a a*, to ensure the plunger working truly in its case; the spears *b* need only be long enough for the engine to make its stroke.

l, is the H piece between the plunger and clack pieces.

m and *k* are the two clacks in their seats, *p* is the windbore receiving water from the cistern *v*, and *d* shows the rising main of the forcing set.

bolts, and at right angles to them. The bolts are made square, and tightly fit the holes prepared for them. The rods work through fixed guides to steady and keep them straight. Where the rod passes through the guide it is cased with hard wood about $1\frac{1}{2}$ inches thick, which may be replaced when worn, and these parts are well greased to lessen the friction. At intervals strong safety-catches are provided to prevent the fall of the rods downwards in case of accident. These consist of short upright balks bolted to the pump-rods, and, at a point just below that reached when the rods are at the bottom of the stroke, strong cross-beams are fixed in the shaft. The method of attaching the spears to the bucket in a lifting set is by means of an iron rod fitting to the bottom of the spears, and secured by bolts as at the joints of the spears, but at the other end of the iron rod alluded to is half a joint which fits on to the corresponding half-joint above the bucket-sword shown at Fig. 283.

Fig. 282.—Scarfed Joint.

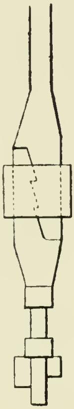


Fig 283.—Clasp-joint for Attaching Bucket Rod to Foot Rod.

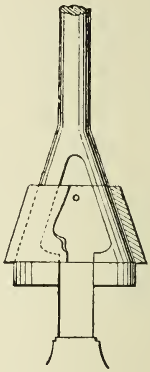


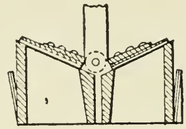
Fig. 284.—Heart Joint for attaching Bucket Rod to Foot Rod.

This mode of joining is sometimes called a "side-joint" or "clasp-joint" to distinguish it from another form called a "heart-joint," shown at Fig. 284. In both a tapering ring of iron, somewhat similar to that used in capping pit ropes, which has been described, is dropped over the joint to prevent its parting.

Large balks of oak, single, or two placed one above the other, are fixed across the shaft to carry each forcing set of pumps. For the same purpose, in heavy pump-work, wrought-iron box-girders are often used. They have to bear a great weight in some cases,—the weight of a long column of pumps with the contained water. Where circumstances admit of it the bottom forcing set may rest upon a good foundation made of ashlar. The diameter of the ram-case is usually rather larger than that of the suction or discharge-pipes, and where the water is corrosive the plunger should be encased in brass. The bucket, as stated, works in the working barrel, which is accurately bored out so as to ensure the bucket working truly in it, and to prevent unnecessary friction. Sometimes the working barrels are lined with brass or gun-metal, which greatly adds to their efficiency. The bucket (see Figs. 285 and 286) is packed with rings of leather to prevent leakage, and, in the common butterfly form, is furnished with two falls on the top made of iron faced with leather, the falls working on a hinge in the centre of the bucket on the top (see sketches). The hole in the bucket-rod through which the hinge-pin passes, is slightly oblong to allow the falls to lift a little in opening. Sometimes the buckets are made of brass. The clacks are

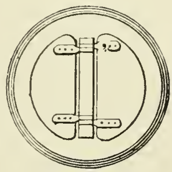
usually made of brass, and have two wrought-iron falls faced with leather, similar to those of the bucket. The clacks must fit accurately in their seats, and as they remain at rest, the falls only opening and closing with the motion or weight of the water, no leather packing is required.

In other respects a clack resembles a bucket, a sketch of which is given. In the larger fittings, valves, single or double beat, are substituted for the clack. In the single-beat valve the lift is about $\frac{1}{8}$th of the diameter of the valve, and in the double-beat, from $\frac{1}{10}$th to $\frac{1}{12}$th. The valve should fit easily on the spindle. The great object, of course, to be attained by the valves is an uninterrupted passage for the water in its ascent, and the prevention of leakage of the valve when closed. It is important that all clacks or valves should be large in diameter, so as to give ample water-way, and with as small a lift as possible to prevent shocks. Platforms may be erected in the shaft for the examination and renewing of the clacks, buckets, and for packing the plunger. Where the clack and bucket doors are very heavy they may be suspended by chains with tightening screws for convenience in taking them off and putting them on again, or a winch from a recess in the shaft may be applied instead of tightening screws.



BUCKET SECTION.

Fig. 285.



BUCKET PLAN

Fig. 286.

The pipes of a lifting set should be at least an inch larger in diameter than the bucket to allow of the bucket being lifted up through the pipes. Where plunger pumps are used it is customary to make the lowest set of pumps a short lifting set, so that in the event of the bottom lift being drowned by a rise of water through accident, the bucket can be drawn up through the rising main. If a forcing set were placed at the bottom, the rise of water a few feet would cover all its valves, and if these failed at such a time, the whole might be lost, or at least, necessitate the employment of divers to get at them. The lifting set lifts the water from the sump to a cistern fixed or built on the next level. In some cases the delivery-piece is bell-mouthed at the top with an opening at one side delivering into the cistern along a wooden trough or landing box placed for the purpose; in others the delivery box is fitted accurately to the top pipe, which is an ordinary one. From this cistern branch-pipes lead to the forcing set (unless the windbore of the forcing set is placed directly in a cistern in the shaft which requires no branch pipes) and by it the water is raised a stage to another cistern, and so on from stage to stage. All the sets of pumps except the bottom one are forcing sets. The size of the spears is regulated by the work required of them, and for large sets of pumps, from 20 to 24 inches in diameter, they are made from 12 to 15 inches square. From the main spears in the shaft the rams at the several levels are connected by means of a set-off secured by strong iron straps. A balance bob consists of a beam of iron or timber 20 or 30 feet long turning on an axis at its centre. One end of the beam is attached by means of radius rods to the spears, and the other to a box containing old iron, or other material of the necessary weight. As the spears descend they have the weight at one end of the balance bobs against them. In the upstroke this weight is an assistance. To ascertain the weight with which to load the balance bobs, it is necessary to take into consideration the relative weight of water in the rising mains, and the total weight of the rods. If the latter much exceed the former, the weight placed to counterbalance by means of the balance bobs must reduce the excessive weight of rods, which, however, must always exceed that of the water in the rising mains sufficiently to overcome friction and cause the down-stroke in the pit or the up-stroke in the engine-house, with a Cornish Beam Pumping engine. With a

double-acting engine, where the force of the steam is used equally on both sides of the piston, the more nearly the weight of the water in the rising mains corresponds to the weight of the rods, the better, so that the engine in that case may have an equal amount of work to do during both portions of the stroke.

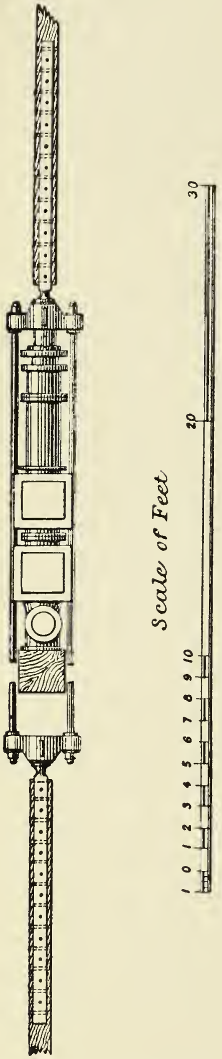


Fig. 287.—Arrangement of Forcing Sets of Pumps in a Shaft.

It is a good plan to fix an air-cock on the top of the working barrel. Air vessels are sometimes placed in connection with the forcing sets of pumps. An air vessel should be placed vertically on the delivery side of the top clack and should have at least five times the cubical contents of the stroke of the plunger, and to be efficient must be charged at a pressure equal to the column of the rising main. If charged with air at its ordinary density, the air vessel is of very little use, and it is rather difficult from its position in the shaft to keep the air of a proper density. The action of the air vessel is this :—As the plunger descends, a part of the water, after passing through the clacks, enters the air vessel instead of flowing up the rising main. In the up-stroke of the plunger, the upper clack shuts and the flow of water for sometime is maintained in consequence of the relief from the pressure which forced it into the air vessel. The advantage of the air vessel then is that it forms a cushion to resist the blow of the plunger in its down-stroke and ensures the more equal flow of water in the delivery pipes. The water in the delivery pipes where no air vessel is used is only in motion during half the time the engine is working, but with an air vessel the water is in motion nearly the whole time, which permits of smaller-sized delivery pipes being used.

To economise space in the pit, the lifts may be fixed in one perpendicular line instead of as shown in Fig. 281. In this case the rods immediately above the plunger and those immediately below are connected by side rods of wood or iron. Fig. 287 shows this method where thick round iron side-rods are secured by screws and nuts to two crossheads strongly attached to the plunger. By this arrangement the rods are in the direct line of their work from the main beam downwards, a one-sided strain is avoided, and the shaft is left more free for other purposes than where a number of sets are taken off in various directions from the main rods.

If the shaft in which the pumps are placed is to be used for a winding shaft also, the pump space should be bratticed off. This divides the shaft into two unequal compartments, the smaller of which serves for the pumps. There are two methods of constructing the brattice in the shaft, viz. the bunton system and the plank system. In the bunton brattice, stringing planks which are deal battens 7 inches × 3 inches in section are fixed to the sides of the shaft, one on opposite sides, from the top to near the bottom. To fix these securely, holes must be drilled in the walling at least 12 inches deep, and these holes are afterwards plugged with wood to receive the spikes which secure the stringing planks to the sides of the shaft. At points of the shaft that have metal tubbing, the stringing planks are nailed to the joints of the tubbing.

Notches are cut out of the stringing planks every 3 feet apart for the purpose of receiving other buntons, which are placed horizontally from the one stringing plank to the other across the shaft. These horizontal buntons are nailed to the stringing planks, and cleading of fir boards from 1 to 2 inches thick are nailed vertically to the horizontal buntons. The fir boards are either planed smoothly at their edges to ensure a close fit, or if one compartment of the shaft is to be used as a downcast and the other as an upcast, to prevent leakage, these boards may have a groove ploughed in their edges, and a slip of wood which fits in the groove is inserted as the brattice is progressing.

In the plank brattice, no horizontal buntons are used, and the stringing planks, instead of being fixed singly, one on each side of the shaft as in the last case, are placed in pairs on either side of the shaft, a space of 3 inches being left between them. Memel planks 3 inches thick are then guided down edgeways through the space formed on the opposite sides of the shaft by the stringing planks to form the brattice. The brattice planks are kept in position by having their edges planed smooth and by using iron dowels, or the joints may be made true as in the manner described for bunton brattice. The plank brattice makes a stronger and more permanent division of the shaft than the bunton brattice.

Pumps for a sinking pit are somewhat different from the permanent arrangement. Either the whole set of pumps or the bottom part must be hung in the pit so as to follow the progress of the sinking. A lifting set is invariably used in the bottom of a sinking pit; and as the sinking progresses over 40 fathoms, a permanent forcing set may be placed at that level, and the lifting set used again for another stage, supplementary spears to work the bucket being attached to the main spears. A method of hanging the pumps in a sinking pit is by two ground spears, fixed one on each side of the set by iron collars. At the top of each of the ground spears is one of a pair of 5 or 7-fold blocks called ground blocks, the other being placed on buntons at the top of the pit. Through these blocks a pair of ropes are rove, the bottom ends being connected to the ground spears and the surface ends of each being taken to a ground crab. The ropes are called ground ropes. The pumps are steadied in their position by means of temporary buntons or collarings. The top pipe or pump is called a "hogger." It is bell-mouthed on the top, and just below at the side is provided with a flexible hose to accommodate itself to the varying height of the column. As the sinking proceeds, the pumps are lowered by the ground crabs, and when the hogger pump is down nearly to the delivery drift, it is taken off by means of the main crab, and lifted over the top of the spears. To allow of this being done readily, instead of the spears being attached to the engine beam, they are clamped to the front of a piece of wood called a Y. A length of pump is then added to the column, a length of spears being added as required, and the hogger pump replaced.

To avoid hanging the whole column, an arrangement, whereby the suction and three following pipes only are suspended, and all other parts are fixed by buntons, is often used. This is called a "sliding suction," that part being made telescopic. When it is necessary to add a pipe, it is put in by breaking the joint above the bucket door and lowering the parts below this to admit of the new pipe. The engine must not be driven faster than is necessary to keep down the water, or too much air will be drawn into the pumps to the injury of the working parts. If it is desirable at times to lower the water below the level of the upper holes of the windbore, these should be carefully plugged first with soft wood.

Figs. 288 to 297 show details of pump-work made by Messrs. Thornewill and Warham, Engineers, of Burton-on-Trent.

Fig. 288 is a sliding windbore used in connection with a bucket set when sinking. The snore-piece is made very strong to prevent its being broken by pieces of rock striking it when the sinkers are blasting, and it has a hand-hole fitted with

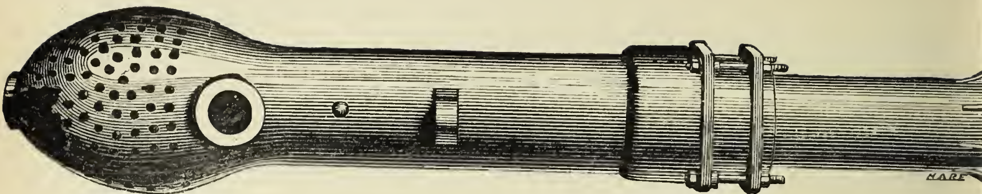


Fig. 288.

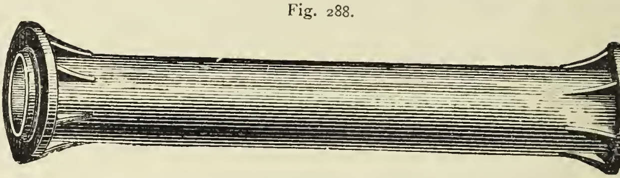


Fig. 289.

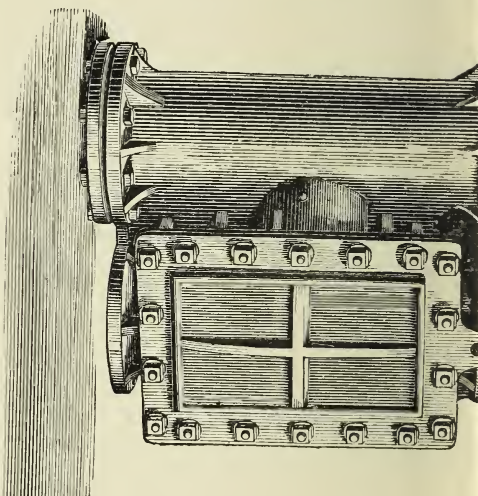


Fig. 290.

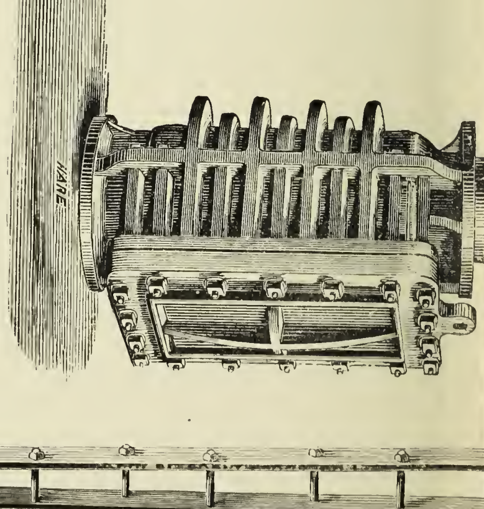


Fig. 291.

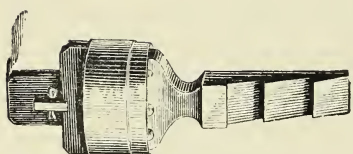


Fig. 292.

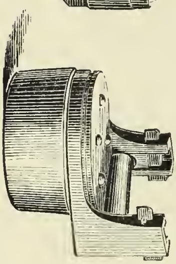


Fig. 294.

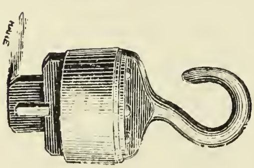


Fig. 295.

Messrs. Thornewill and Warham's Details of Pump-Work.

Fig. 293.

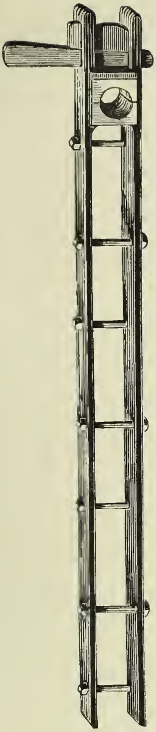


Fig. 296.

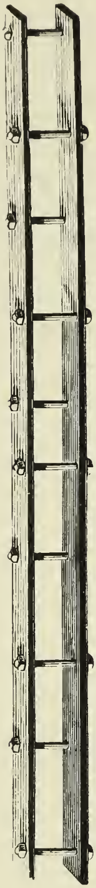


Fig. 297.

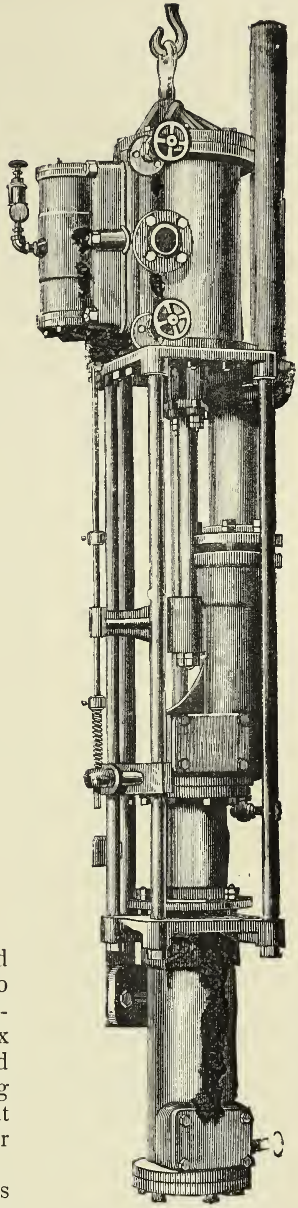


Fig. 298.—The Deane Sinking Pump.

a wooden plug. On withdrawing the plug, the hand may be passed through the hole to the inside so as to clear the snore-holes when necessary. The lower portion slides up or down by means of a stuffing box which is usually packed with spun yarn and luted (sealed) with clay. The lug shown on the drawing above the hand-hole forms a means of attachment for the suspending rods, which serve to raise or lower the bottom portion of the slide-piece as required.

Fig. 289 is a working barrel with bracketed flanges and spigot and socket joints. It is bored to gauge and bell-mouthed at each end so that the bucket may be easily led into the barrel bore.

Fig. 290 is an H piece for a plunger set with a clack-box and a portion of the plunger or pole case attached by a branch.

Fig. 291 is a clack-piece for either a bucket or plunger set, and is well ribbed for deep lifts.

Fig. 292 is a bucket with sword and half of clasp joint for attaching to corresponding half on upper rod as shown in Fig. 293. The buckets have leather falls

shod with iron, and bucket packing of leather held in place by a wrought-iron hoop with crossbar.

Fig. 294 is a clack for a plunger-lift, and may be used for a bucket-lift when it is not necessary to draw the clack up through the working barrel, in which latter case a clack as at Fig. 295 is fitted. Both clacks have leathers shod with iron plates securely riveted thereto.

Fig. 296 is a pair of strapping plates for bolting to the wood spears and having fitted a pair of gun-metal boxes for attachment to the gudgeon of a T bob.

Fig. 297 shows the ordinary strapping plates and bolts for connecting the various lengths of wooden spears.

The Pulsometer Engineering Company make a special form of sinking pump called the "Deane" double plunger and shown in Fig. 298. It is designed to raise water from depths beyond the range of the pulsometer, and as it takes up but little room, will be found very serviceable in small-sized shafts of limited depth. It will work either when hanging from tackle as shown in the figure or when attached to the timbering by means of the "dogs" with which it is provided.

The pump is driven by a vertical steam cylinder with its piston, the strokes of which are perfectly regulated by controlling valves. This piston imparts a reciprocating motion to the barrel beneath and at the same time to the lower plunger to which it is attached. This plunger is hollow, but has a valve opening upwards at its upper extremity. The barrel beneath the piston of the steam-engine works over an upper plunger, which is hollow and of smaller size than the lower. A valve is placed below the lower plunger. The operation of the pump is as follows:—On the up-stroke the water runs from the suction-pipe through valves and occupies the displacement of the lower plunger while the contents of the upper barrel are forced up through the upper plunger and discharge-pipe. On the down-stroke the water in the lower barrel is forced through the valve at the upper extremity of the lower plunger, and as the displacement of the lower plunger is double that of the upper, one half is discharged at the delivery pipe while the other half is accommodated in the upper barrel. Thus water equal to the displacement of the upper plunger is discharged at each single stroke of the machine. By the construction of the pump the water is forced up and through its several parts almost in a straight line, doing away with all friction incident to circuitous and intricate passages.

Various kinds of engines are used to work the pumps. Fig. 299 shows a side elevation of the Cornish Pumping Engine. The following description is chiefly taken from André's treatise on *Coal Mining*, as also the drawing, Fig. 281, usually associated with that of the Cornish Pumping Engine. The cylinder F is 70 inches in diameter with a 10-foot piston stroke. It is provided with a cast-iron steam jacket connected to the boilers by means of the pipe H. The boilers are situated below the pipe H, so that the water of condensation returns by it. Where the boilers from unavoidable circumstances are above the cylinder, the supply-pipe to the steam-jacket cannot serve as a return condensed water pipe, and provision must be made for freeing the jacket from condensed water. This will be best done by means of a steam trap. The steam-jacket is encased in wood, the annular space between the two being filled by some non-conductor of heat such as sawdust, and the whole is enclosed by brick-work either in contact with the wood casing or separated from it by a few inches and is plastered on the outside and covered with wood panelling. The cylinder cover is fitted with a false lid or cap which encloses a thick layer of sawdust and is thus protected from the cooling influence of the air. The space under the cylinder bottom is protected from the same influence by steam filling it from a branch of the pipe H. C is the main beam, cast in two plates which are bolted together, with distance blocks

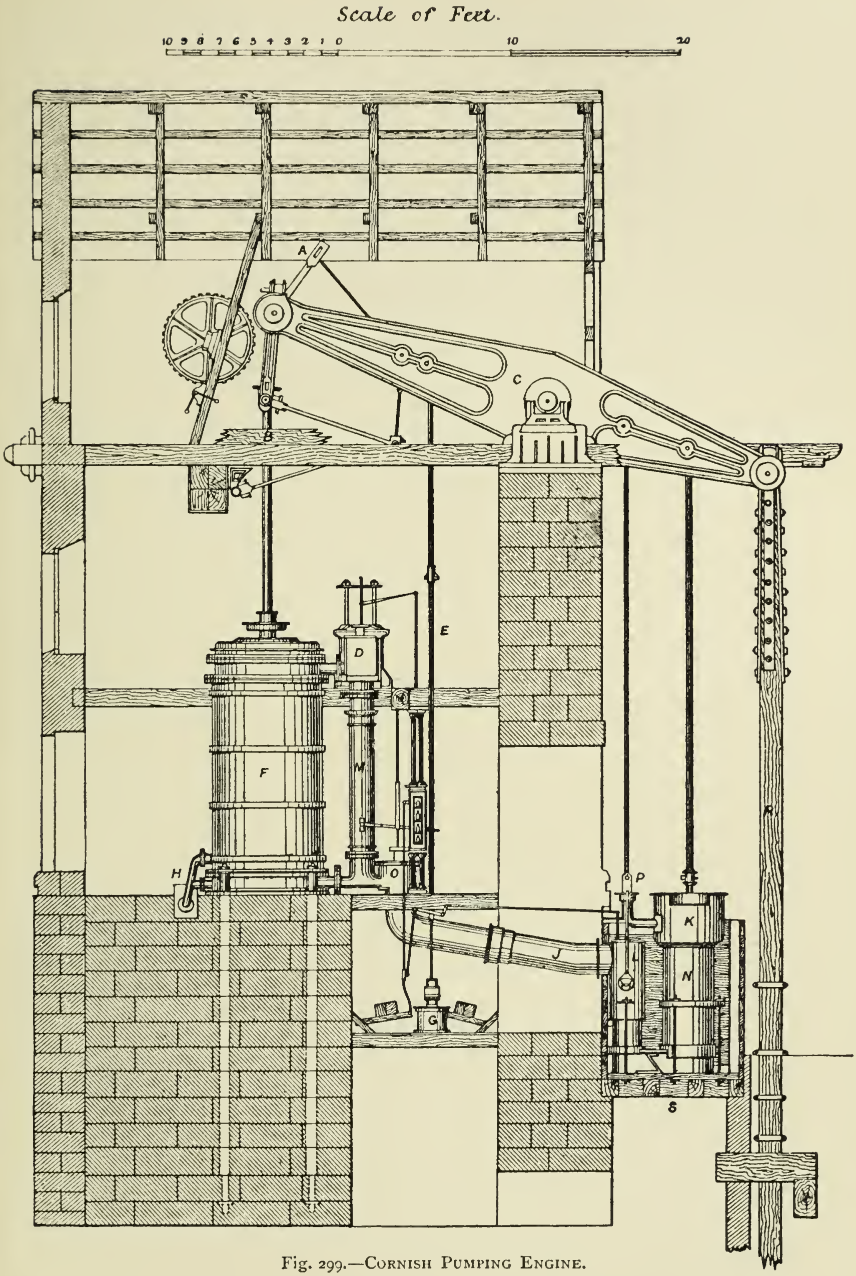


Fig. 299.—Cornish Pumping Engine.

between to keep them truly parallel. A catch-piece, A, is fixed to the upper part of the beam by means of brackets. On the piston reaching the bottom of its stroke, the catch-piece touches the blocks B, fixed on the spring beams, arresting the piston and thus preventing injury to the cylinder by the engine making too

long an in-door stroke. E is the plug or tappet-rod for working the valves and cataract, and D the top nozzle shown also in section in Fig. 300. The nozzle contains three valves. G (Fig. 300) is the governor or regulating valve, for regulating the admission of steam into the chamber E E of the nozzle, whence

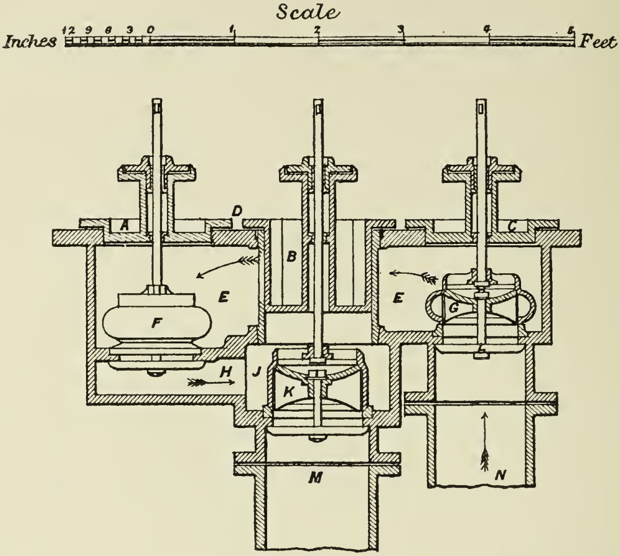


Fig. 300.

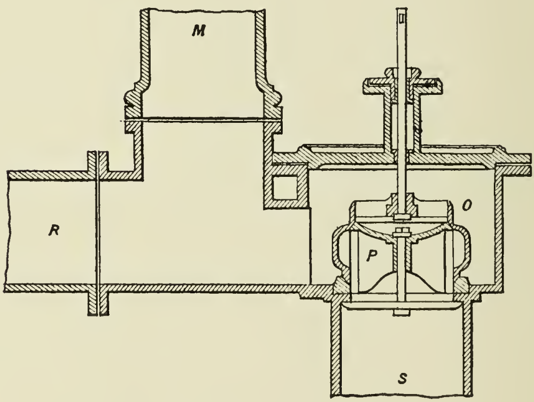


Fig. 301.
Cornish Pumping Engine Valves.

it afterwards passes through the steam valve F into the cylinder. The governor-valve is not moved by the engine during its working, but is regulated occasionally by hand. In proportion to the raising of the governor-valve more or less, the steam is less or more wiredrawn or reduced in pressure in its passage from the steam-pipe into the cylinder. By this means, although the boiler pressure may vary, the mean effective pressure in the cylinder will be kept more constant.

The motion of the governor-valve is under the control of the engine-man, and

a handle is placed within his reach which is connected by a rod and a lever with the valve-spindle.

F (Fig. 300) is the steam-valve which admits steam into the cylinder. The chamber E E is not separated by the cover B, as may be thought from the drawing, but an uninterrupted passage is afforded for the steam through the chamber E E, as shown by the arrows. On the steam-valve F being lifted (if the governor-valve is also open), the steam is free to pass through it from the chamber E E to the passage H, and thence by the steam-port J into the upper part of the cylinder. K is the equilibrium-valve, and is situated in the middle of the nozzle. On being lifted the steam above the piston is free to find its way along the equilibrium-pipe M (Figs. 299, 300, and 301), and by the lower port into the lower portion of the cylinder under the piston. At the moment the pressure of the steam above and below the piston become equal, the rods R (on account of their weight) hung at the other end of the beam descend, and the piston is drawn upwards, the steam above it acting as a cushion in its ascent.

The upper nozzle D has an external casing of thin iron, a space being between it and the nozzle which is filled up with sawdust or some other non-conducting material to retain the heat.

A reference to Fig. 300 shows that the three covers C, A, B, which are bolted to the nozzle over the governor, steam and equilibrium valves respectively, are of such a size as to allow of the valves being examined or repaired on removing the covers. O is the bottom nozzle (Fig. 299), and shown in section in Fig. 301. In it is placed the exhaust-valve P for opening or closing the communication between the lower part of the cylinder and the condenser. Above the valve the nozzle-chamber O is in communication with the cylinder by the lower port, and under the valve the bottom of the nozzle communicates with the eduction-pipe J on Fig. 299, S on Fig. 301. When the exhaust-valve is raised the steam in the lower part of the cylinder is exhausted into the condenser L.

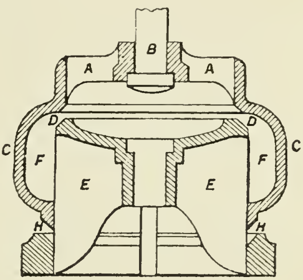


Fig. 302.—Cornish Pumping Engine. Enlarged sketch showing Vertical Section of Equilibrium Valve.

That the action of the Cornish valve may be rendered plainer to the student, an enlarged section of one is given in Fig. 302. The valve is designed to give a large extent of opening for the passage of steam with little traverse, a small amount of power being necessary to work it. E is the fixed seat, made of cast-iron or brass, which forms part of, or is secured to, the valve-chamber. C is a bell-shaped valve-piece, also of brass, actuated by a rod, B. The valve is in contact with its seat at two places, D and H, which are formed into accurate conical surfaces, the one, D, being internal, the other, H, external. When the valve is closed these surfaces accurately fit similar ones on the seat, and when lifted, as shown in Fig. 302, two annular openings are formed at the same time, thus giving a double passage to the steam through the valve. The spindle, B, of the valve, C, is fixed to a centre eye, cast in one with the valve-piece, and connected to it by four arms, A A being two, the others being at right angles to them. The seat is also formed similarly with four arms, having an annular ring at the base, the top edge of which is bevelled and ground to fit the lower edge of the valve, C, and when lifted forms the opening, as shown at H.

Referring again to Fig. 299 it will be observed that the piston-rod is connected with the end of the beam by a parallel motion which ensures the ascent and descent of the piston-rod in a vertical position whilst the end of the beam moves

through the arc of a circle. A very striking feature of the Cornish engine is the cataract governor, G (Fig. 299), shown also in section in Figs. 303 and 304. This and the parallel motion were the inventions of Watt. It consists of a pump placed in a circular tank of water below the level of the cylinder. G is a barrel, and F the plunger working in it as in an ordinary small forcing pump. The water reaches the barrel through the inlet-valve, H, which opens freely upwards, but the passage for the outlet is contracted as desired by a moveable plug, L. The plunger is connected by a joint to the lever, A. This lever is loaded with a heavy weight, C, on the same side of the fulcrum as the plunger, and the lever projects on the other side of the fulcrum, terminating in the handle shown on the drawing. When the tappet or plug rod, D (which is worked off the main beam), has descended nearly to the end of its stroke, a projecting block on the lower part of it, E, called a tappet, strikes the end of the lever, A, and in consequence the plunger, F, is raised, the water flowing freely through the valve, H, and following the plunger in its ascent. After the completion of the down stroke the piston of the

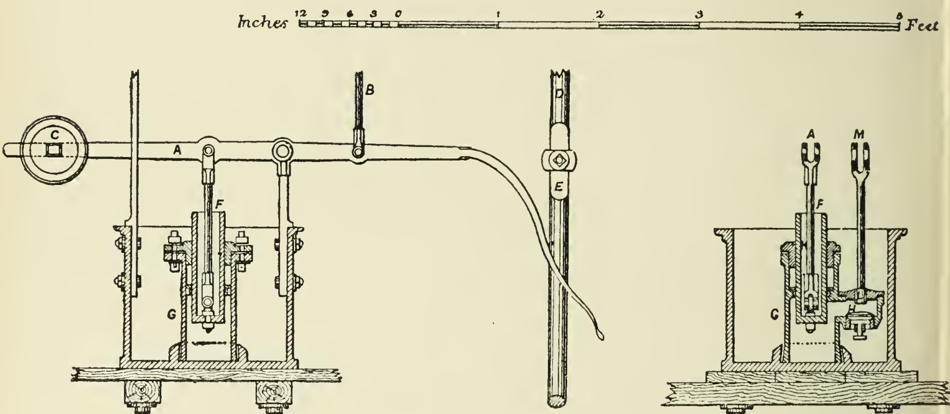


Fig. 303. Fig. 304.

Watt's Cataract Governor for Regulating the Speed of the Cornish Pumping Engine.

engine begins to ascend (due to the opening of the equilibrium-valve by the tappet-rod), the tappet-rod also ascends, and leaves the lever, A, and the heavy weight, C, which was raised at the same time as the plunger, becomes the motive power in driving the water from the pump by forcing down the plunger. The inlet-valve, H, having closed before the descent of the plunger, the only passage for the water is by the aperture left round the regulating plug, L. It will be seen, therefore, that the time occupied by the pump-plunger in its descent depends upon the size of this aperture, which the attendant regulates by means of the plug fitting it. Near the fulcrum of the lever, A, but on the tappet-rod side of it, a rod, B, is jointed to the lever, and ascends vertically from it. In its ascent this rod opens first the exhaust, and shortly afterwards the steam valve, thus causing the engine to commence the next down-stroke. The rod, B, acts upon a catch that releases weights which, by their fall, open the valves, causing a suddenness of action for which considerable advantage is claimed, especially as regards the admission of steam into the cylinder by the steam-valve. The interval of time between any two consecutive strokes must, therefore, depend upon the time occupied in the descent of the cataract-plunger, and upon the amount of opening given to the regulating plug, L. By means of a micrometer screw and handle connected with L by a rod and the lever, M, the plug can be regulated to any degree of opening required. The steam-valve can thus be opened any desired

number of times per minute, and the number of strokes in that interval of time thereby regulated.

J (Fig. 299) is the eduction-pipe, connecting the condenser, L, with the bottom of the exhaust-valve nozzle, O. The size of the air-pump, N, is approximately half that of the steam-cylinder, being 2 feet 9 inches in diameter, with a 5-foot stroke. It is fitted with a foot-valve. P is an ordinary plunger feed pump. The condenser, L, is fitted with an injection cock and valve for regulating the cold-water supply to it. The pump-rods, R, are frequently attached to the main engine-beam, as shown on the drawing, without the intervention of a parallel motion, and with only side guides in the shaft. The consequence is that near the surface the rods deviate considerably from a vertical line in their ascent and descent, but this deviation is less at lower portions of the rods. It is a much better plan for the pump-rods to be attached to the main beam by a parallel motion, so as to ensure the rods maintaining a vertical position. This may be done by a gudgeon on top of the rods carrying two side-blocks working in cast-iron guides for a sufficient length to take the stroke of the engine. The gudgeon may be attached to the beam by two iron radius-rods, the space between them being filled with pitch pine.

Husband's Patent Gearing may be applied to the engine. In the event of breakage this gearing is intended to open the equilibrium-valve, and stop the engine.

The steam in the Cornish Pumping Engine is admitted at high pressure, and may be worked expansively, the steam being cut off at some point of the stroke, which may be from one-sixth to one-third. In consequence, however, of the great shocks to the engine, and especially the pit-work, when a high rate of expansion (with its accompanying high velocity during the stroke), is attempted, which shocks lead to breakage and stoppage of the pumps, it is not found advantageous to work at any but a very moderate rate of expansion, and thus economy of steam is sacrificed for the sake of safety in working. The Cornish engine being single-acting it necessarily requires a larger cylinder for a given amount of work than a double-acting engine. As regards fuel consumed it is economically worked, from 3 to 6 lbs. of coal being used per hour per indicated horse-power.

The Cornish Pumping Engine is a wonderfully elaborate and complicated specimen of ingenuity and skill. Where permanent working can be assured by a continuance of the working conditions and requirements of the mine, it well remunerates the enormous outlay necessary in purchasing and erecting the immense structure. The cost of a first-class Cornish engine is about £8 per H.-P.

A 90-inch or 500 H.-P. engine therefore costs about £4,000; then the three-storied engine-house and pillars for such engine would require about 500 cubic yards of building, the price of which varies in different localities, according to the character and price of materials such as stone, brick, lime, &c. In Cornwall, where suitable stone abounds, it seldom exceeds 6*s*. 6*d*. per yard. Again, the steam case must be covered with some non-conducting material, or else, having a greater surface-area than the steam cylinder, it becomes a large condenser.

Another objection to the Cornish engine is the large number of parts to maintain in an efficient state of repair and cleanliness. It has four double-beat valves with their sets of bright nozzle gear, consisting of pillars, levers and guides, quadrants and catches on the ground-floor, tappet-rod carrying its adjustable blocks to work the four levers of double-beat valves and cataract governor in the basement; air-pump and condenser with foot and delivery valves, injection cock and valve and lever attachments; also a large cast-iron beam, which for a 90-inch engine weighs 30 tons, and the parallel motion with its many joints, all requiring a considerable amount of attention and care.

Davey's Patent Differential Valve Gear may be applied to work the valves of

the Cornish as well as to other engines, thus doing away with the tappet gear. A perspective view of it is shown at Fig. 305. A lever (*a*) called the main lever, gives motion to the valves through a rod (*b*). The motion of the engine is given to the outer end of the lever through the rod (*c*), by means of a lever of the first order, the long end of which is attached to the plug rod or any moving part of the engine, where it gets the motion of the piston on a reduced scale; the other

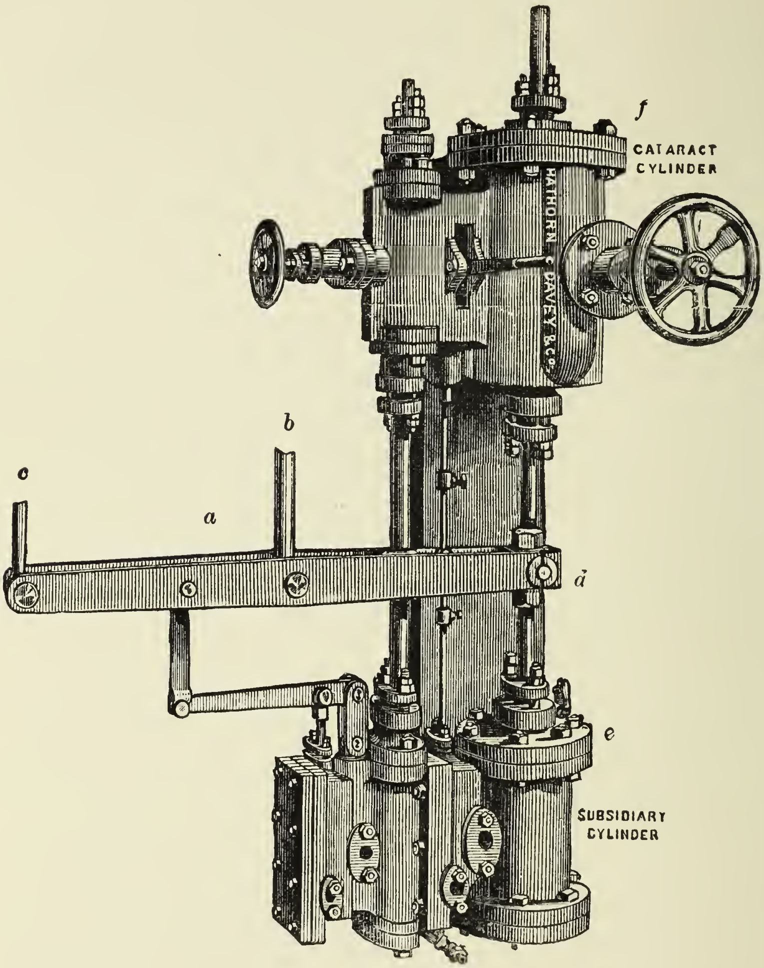


Fig. 305.—Davey's Differential Valve Gear as applied to work the Cornish Engine.

end (*d*) deriving its motion from a subsidiary cylinder (*e*), and being controlled by means of the cataract (*f*). The cylinder has a slide valve, which is worked by means of a tappet arm on the rod of the piston of a secondary cylinder; the motion of the secondary piston is also controlled by a secondary cataract. The slide valve is, however, free to move with the motion of a hand lever.

It will be seen that there are two hand wheels and a lever attached to the cataracts. The function of the large wheel is to regulate the speed of the engine during the stroke, the small wheel is for regulating the pause between the

strokes, whilst the hand lever enables the engineman to work the engine by hand, if necessary. A rocking shaft, not shown in the engraving, is employed to give motion to the valves of the engine in the usual way.

The action of the gear may thus be described:—Let the engine be "out doors." * The engine end of the main lever will then be in its highest, and the opposite end in its lowest position, the secondary lever being lifted so as to admit steam to the bottom of the secondary cylinder. The engine will pause until the piston of the secondary cylinder has travelled to the end of its stroke, and lifted the valve of the subsidiary cylinder. The pause will be long or short, according to the regulation of the secondary cataract. The piston of the subsidiary cylinder then having steam on its lower surface will travel upwards, actuating the main lever with a speed dependent on the adjustment of the cataract. In doing so, the steam valve of the engine will be opened by means of the rod (*b*), and a rocking shaft, &c., and will be opened quickly, because the engine end of the lever is, for the time being, stationary. Steam now being admitted on the engine piston, it will, after overcoming the inertia of the load, move off at an increasing speed, which is communicated to the engine end of the main lever. The result is that as the opposite end of the lever is moving uniformly in the opposite direction at the same time, the motion of the centre is soon reversed, and the steam valve, which was opened by the motion of the subsidiary piston, is closed by the differential motion brought into action by the motion of the main piston acting on the same point.

Steam engines (such as the Cornish Pumping Engine, just described) in which the exhaust steam is conveyed to a condenser and afterwards removed with the air liberated in the process of condensing by the air-pump have a vacuum gauge fitted to them, as a means of indicating the amount of vacuum obtained.

If it were possible to have a perfect vacuum by using the air-pump we should have registered on the gauge about 30 inches or nearly 15 lbs. pressure per square inch, and the more nearly this reading is approached the better the attempt at producing a vacuum. The air-pump, however, never exhausts all the air from the condenser; what is left is in a highly attenuated state, and this prevents the gauge ever registering so great a pressure. Vacuum gauges are more particularly described in Chap. XIV. of this work.

The Cornish Bull engine is a type of pumping-engine in which the beam is placed below the cylinder and the spears are on the same side of the beam as the cylinder A weight is placed on the other end of the beam. It is a double-acting engine and has the assistance of the vacuum as well as the pressure of the steam during the up and down stroke of the piston. It does not require the expensive pillar necessary for the single-acting Cornish engine, and being double-acting a cylinder of half the size will do an equal amount of work. The cylinder is placed vertically. A serious objection to the Bull engine is that it stands right over the pit, the piston-rod forming one line with the spears.

Another kind of Cornish engine seems to be a combination of the two described. In it the beam is placed under a vertical cylinder, the spears in the pit being at one end of the beam, the cylinder at the other. This removes the objection of the engine being placed over the shaft, and very expensive pillars are not required. This is a double-acting engine.

* It is customary to speak of the Cornish engine as being "out-doors" when the piston has reached the top of its stroke, and "in-doors" on its descending to the bottom. In the case of a horizontal pumping engine, the out-door stroke takes place when the connection between the engine and quadrant moves away from the engine-house towards the shaft, and the-indoor when the motion is reversed.

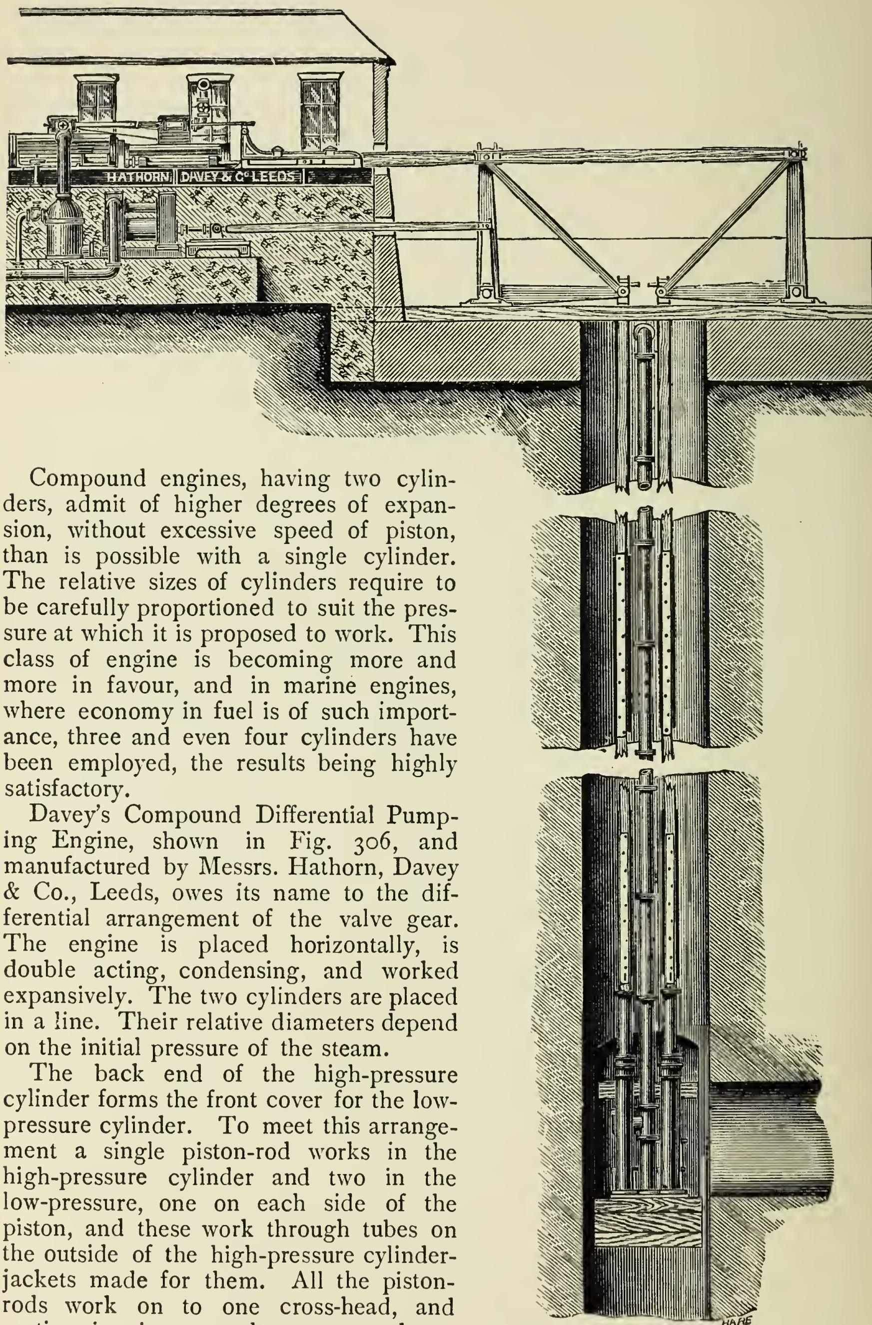


Fig. 306.—Davey's Compound Differential Pumping Engine.

Compound engines, having two cylinders, admit of higher degrees of expansion, without excessive speed of piston, than is possible with a single cylinder. The relative sizes of cylinders require to be carefully proportioned to suit the pressure at which it is proposed to work. This class of engine is becoming more and more in favour, and in marine engines, where economy in fuel is of such importance, three and even four cylinders have been employed, the results being highly satisfactory.

Davey's Compound Differential Pumping Engine, shown in Fig. 306, and manufactured by Messrs. Hathorn, Davey & Co., Leeds, owes its name to the differential arrangement of the valve gear. The engine is placed horizontally, is double acting, condensing, and worked expansively. The two cylinders are placed in a line. Their relative diameters depend on the initial pressure of the steam.

The back end of the high-pressure cylinder forms the front cover for the low-pressure cylinder. To meet this arrangement a single piston-rod works in the high-pressure cylinder and two in the low-pressure, one on each side of the piston, and these work through tubes on the outside of the high-pressure cylinder-jackets made for them. All the piston-rods work on to one cross-head, and motion is given to the pump rods or spears by means of two quadrants or L pieces, working two sets of pumps. The engine does not require expensive foundations. In one arrangement the low-pressure engine piston has a rod passing through its back cylinder cover

called a "tail rod," which works the air-pump and condenser, which are placed on a separate bed, behind the low-pressure cylinder. With large engines, the air-pump and condenser are placed by the side of the engine and under the engine-room floor, as illustrated in Fig. 306.

Davey's shutter valve may be applied to pumping engines. By its means the engine is enabled to do more work on one side of the stroke than on the other, and is especially useful when the engine is used for sinking operations, as it enables the engineman to adjust the steam supply whilst the engine is running, and cause it to work uniformly, even though the pumps may be constantly put out of balance by the sinking operations. In the Differential engines intended for sinking purposes one of the quadrants is provided with a balance arm, for the convenience of balancing the engine as the shaft is sunk. To avoid the necessity of altering the balance weight during the progress of the work a shutter apparatus is placed on the back of the main steam valve, enabling the engineman to adjust the relative supply of steam to the two ends of the cylinder, and thereby causing the engine to work uniformly when out of balance.

Davey's safety trip gear is applied to a direct-acting pumping engine in order to check it in the event of the breakage of a spear rod, or to resist the action of a riding column on the pumps. It is applicable to direct-acting engines of all descriptions. By this gear the communication between the high and low pressure cylinders is kept open by a catch which is released by the engine whenever it suddenly increases in speed from loss of load.

The great features of the Differential engine are its differential valve gear and safety trip gear. They admit steam to the engine in proportion to the resistance to be overcome, and in case of a sudden total loss of load, reverse the steam to catch the piston. The distribution of the steam is effected by coupling the motion of the engine with that of a subsidiary piston whose velocity is made uniform by its cataract. The engine is made to cut off steam by its motion, while the uniformly moving subsidiary piston is employed in admitting it. As long as the resistance to the engine is sufficient to prevent its motion from becoming equal to that of the subsidiary piston, steam is admitted up to the fixed point of cut-off; but should a loss of resistance, or an increased pressure of steam cause the engine to acquire a speed relatively greater than the speed of the subsidiary piston, the motion of the steam-valve would be reversed earlier and the supply of steam would be adjusted to the altered conditions. The effect of a sudden loss of load is to reverse the action of the valves and to throw the steam against the motion of the piston, stopping it before the end of the stroke, and this is done by the automatic working of the valve gear. The Cornish engine has no such efficient means of avoiding shocks, and the contrivances for preventing injury to the engine in case of accident are of a rougher description. The Differential pumping-engine gives a uniform speed and prevents all shock; and it does not require so expensive an outlay for the engine-house.

The quadrants connecting the pumps to the engine are constructed of wrought iron, and are so arranged that one plunger makes the up stroke whilst the other is making the down stroke; thereby a continuous stream of water is delivered through the rising main.

The suction and delivery valves and valve boxes are specially constructed to withstand heavy pressures, and are so arranged that they can be readily got at in a chamber by the side of the pit.

The engines are made in all sizes up to 76-inch cylinders, and 10-foot stroke, and have been very largely adopted both for coal and metalliferous mines.

The cost of working a Compound Differential Pumping Engine, supplied to the Yarlside Mining Company, Dalton-in-Furness, including fuel, wages, stores, repairs, and interest on capital at 10 per cent. amounted to less than one farthing per 1,000 gallons raised 100 feet high.

The engine has 33- and 60-inch cylinders with a 10-foot stroke, and it works two 20-inch plunger lifts, each pumping 400 feet high in one lift.

A larger engine of this description has been supplied by Messrs. Hathorn, Davey & Co., to the South Staffordshire Mines Drainage Commissioners. It has a 44-inch high and a 76-inch low pressure cylinder, the stroke being 10 feet, with air-pump and surface condenser, fitted with a large number of 1-inch gun-metal tubes. The condensed water is cleared from grease, and is then used to feed the boilers. The engines work two 19-inch plungers, with 10-foot stroke placed at a depth of 464 feet, forcing the water up an 18-inch column to the surface. The buckets and clacks are of gun-metal and of the Cornish type, with double beats. At each stroke of the plungers 245 gallons of water are raised, and the engine is capable of raising 2,000,000 gallons in twenty-four hours.

The advantages of pumping-engines being placed on the surface are:—a minimum of loss in the steam-supply, the boilers being close to the engines; better supervision and greater facilities for repairs; if the mine should be flooded, and the water rise above the pumps, the engine can work on uninterruptedly; and further, in cases where the heaviest feeders are met with and collected in the shaft, the lifts may be reduced in size from the top lift downwards. The water, perhaps, is pumped out of a shaft by means of a sinking set. The engine obtained for the purpose of working the pumps during sinking may be made to work the pumps permanently.

Pumping-engines are sometimes placed underground. A pit may be sunk comparatively dry, or the water may have been wound out by barrels or "kibbles" during the sinking, and afterwards large quantities of water may be made in the workings. On the other hand, a great advantage of the engine being placed underground is the absence of the cumbersome pump rods or spears, which are both costly in the first instance and in the wear and tear of working. Moreover, the spears limit the length of the column. Another advantage of placing the engine underground is derived from the fact that a much smaller engine will do the work there than on the surface, as the pumps may be always double-acting, and pump-rods being dispensed with, may be worked at a higher speed than engines on the surface. Lodge-rooms and cisterns in the shaft are also not required. In the usual form of pump worked by an engine on the surface the water is only in motion half the time, but with the engine placed underground it is continuously so, and smaller pipes will suffice, although they may require to be made of thicker metal in a long column. A disadvantage in placing the pumping-engine underground is that a disarrangement or accident to the pumps is more difficult to deal with, and also that the engine is liable to be drowned whilst standing. Steam may be conveyed from the surface down the shaft to the engine, or the boilers may be placed underground, but as stated when dealing with steam haulage, it is better to have the boilers on the surface. All large engines for underground pumping and their pumps, and most of the smaller engines or steam pumps, are placed horizontally, an arrangement which takes up little room and gives great compactness. The piston of the engine and the plunger of the pump are generally on one rod. The pumps underground should be double-acting, and it is well to have a pair of engines either of which is capable of working the pumps. The engines may have condensing arrangements or may exhaust into the upcast shaft. If there is no separate condenser, the exhaust steam can be led into the suction water pipe, which will not only get rid of the steam, but assist the engine by forming a partial vacuum. The Compound Differential engines give excellent results when placed underground. They have been made of all sizes of cylinder up to 60 inches in diameter and 8 feet stroke. The engine has frequently been placed, where circumstances have permitted, at a position in the pit above the workings,

and the water made in the latter has been lifted to the main engines by means of a hydraulic pumping engine, deriving its supply from the rising main of the main pumping engine. This arrangement has been adopted by Messrs. Hathorn, Davey & Co., in cases where the workings would be flooded before the water could reach the main engines. The hydraulic engines are so constructed as to work under water. In many cases, the power is supplied to them from accumulators on the surface.

The Worthington Compound Expansive Pumping Engine is thus described in *The Practical Engineer* of Feb. 22, 1889.

Direct-acting steam-pumps of the usual type are wasteful in their use of steam, and do not work so economically as the best expansive fly-wheel engines and pumps. They are, however, very convenient for small powers, and have the advantage of low first-cost and inexpensive maintenance, which may in some instances compensate for excessive steam consumption. Where the steam cylinder is in direct line with the ram driven without the intervention of a fly-wheel, it is evident that throughout the stroke a fairly uniform pressure must be maintained on the piston to overcome the resistance of a constant head of water in the pumps. The full boiler pressure must therefore be carried throughout the stroke, or if this is more than is required to overcome the resistance, the steam must be throttled throughout the stroke.

The Worthington pump is an improvement on the ordinary form of direct-acting steam-pumps, and the objections raised to the use of the latter do not apply to the former. Figs. 307 and 308 show a Worthington pumping-engine designed for large powers and high duty. It is a compound engine, and considerable expansion is obtained in the steam cylinder without the intervention of fly-wheels or other heavy moving masses. Two distinct steam-cylinders and pumps are placed side by side and so arranged that the slide-valve of the one steam cylinder is actuated from the piston-rod of the other. By this means the piston-valves common to other direct-acting pumps are dispensed with and only plain slide-valves used. The two engines act in concert, so that one is always in motion whilst the other is stationary: therefore both valves are never at rest at the same time, and there is no tendency to stop in any position without starting again, whatever speed the pump is working at. The plungers are double-acting, and a continuous flow of water is obtained. The pump works without shock or jar, and almost noiselessly, even against the heaviest pressures. The gear designed to equalise the varying pressure in the steam-cylinder due to the expansion is shown at Fig. 308. It consists of two oscillating cylinders working on trunnions placed so as to be opposite to each other at the centre of the piston-stroke. The pistons working in them are single-acting and are connected to the piston-rod, as shown in the drawing. The motive-power for the oscillating cylinders may be air or water supplied from suitable reservoirs, pressing the pistons outwards. At the commencement of its stroke the full boiler pressure is admitted to the steam piston, and the oscillating or compensating cylinders point in the direction shown in position 1, Fig. 308, and resist the forward motion of the steam-piston. The resistance gradually diminishes as the middle of the stroke is approached, and, when reached, the air cylinders press against each other without affecting the steam-piston, as shown in position 2, Fig. 308. As the steam-piston continues its course beyond mid-stroke, the compensating pistons give out more and more power and assist the steam-piston, their force being greatest at the end of the stroke, when the steam pressure is at its lowest. They are then in position 3. The effort of the steam is resisted at the first part of the stroke and strengthened at the latter part. In the engine shown on drawings four steam cylinders are used, two to each pump, high and low pressure; another form of Worthington pump contains only two steam and two

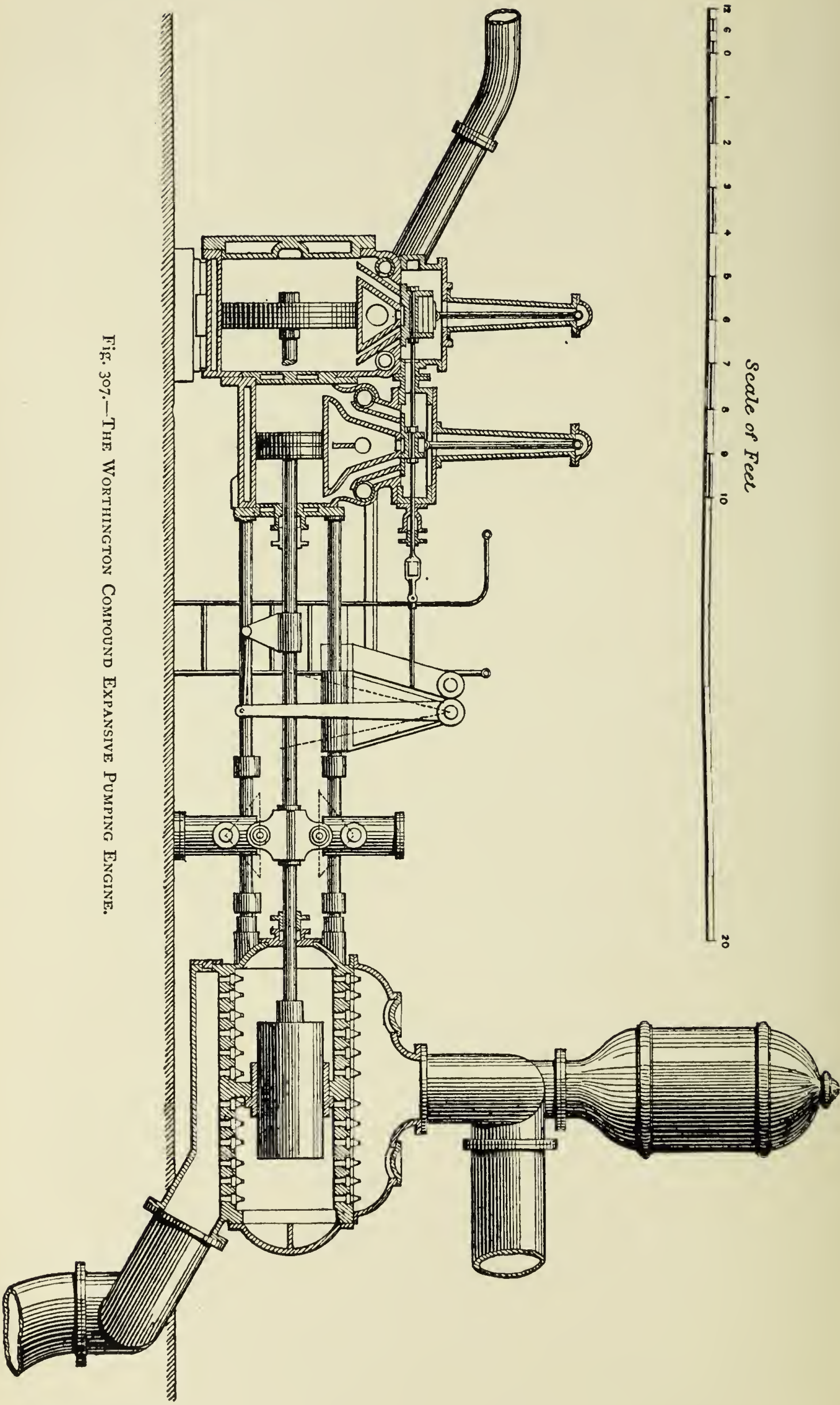
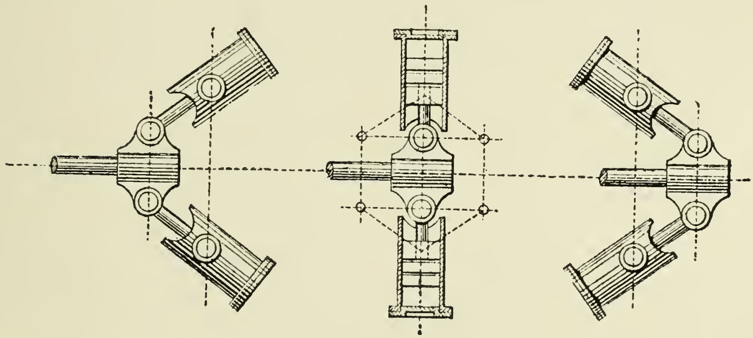


Fig. 307.—The Worthington Compound Expansive Pumping Engine.

water cylinders, but they always consist of two steam-pumps placed alongside each other. In consequence of the slide-valve arrangement, whereby the piston-rod of one cylinder actuates the slide-valve of the other, the pump is always ready to start, in whatever position it may stop, like an engine with two steam cylinders and cranks at right angles.

Double steam-ports are used in the cylinders, the object of which is to cushion the piston and prevent its striking the covers. When the piston passes the first port in its motion towards the cover, it compresses the steam contained and stops. If the second port were not at the end, when the steam-port opened, the piston would not be started. If the first port were at the end, there could be no cushion for the piston.

In a test of the duty obtainable from these pumping-engines, with an engine having a 26-inch stroke, the high-pressure cylinder being 1 foot 6 inches in diameter and the low-pressure 3 feet in diameter, the indicated horse-power of the four



Position 1. Position 2. Position 3.

Fig. 308.—Worthington Compound Expansive Pumping Engine. Oscillating Cylinders to Equalise the Varying Pressure in the Steam Cylinders.

cylinders was 130·5, and that in the pumps 120·4, which is equal to an efficiency of 92 per cent. The piston speed per minute per engine was 86·9 feet; boiler pressure 101 lbs. per square inch above atmosphere, and the number of expansions 14·1. The consumption of coal per indicated horse-power was estimated at 1·7 lb.

Power is transmitted very easily and safely for even long distances by means of compressed air, although only a small percentage, probably not more than from 20 to 30 of useful effect, is obtained. It is an exceedingly suitable and handy means of working pumping-engines, hauling-engines, or coal-cutting machines in the workings of a colliery.

There are occasions when hydraulic pumping-engines can be beneficially applied. Thus, where water is brought to the shaft at a point above the level of the main pumps and has to fall down to the pumps, its fall represents a power proportionate to the quantity and to the depth it falls. In any case where there is a surplus of power in the main pumping-engine a hydraulic may be used for pumping from the dip, the power-pipe being taken from the rising main, or a lodge-room in the shaft or even from the surface. Whatever the source of supply, it should be situated at least 10 fathoms above the discharge at the sump—the more the better for the working of the hydraulic. In many cases where water is available with a head sufficient to give the necessary pressure, small quantities may be raised from dip-workings to the sump. Where the main pump-

ing-engine is already working at its maximum power the hydraulic system cannot be applied.

The usual arrangement for hydraulic pumps is to have the power-piston and the ram on one rod, one behind the other. The valves are specially made and are generally worked by a tappet arrangement. The surplus pressure on the piston over the ram gives its motion; the area of the piston × lbs. pressure of head is in excess of the area of the ram × lbs. pressure of its head + friction. The speed of ram is from 18 to 30 feet per minute. Friction is an important point in hydraulic pumps. The loss of head in forcing water through long pipes is inversely as the fifth power of their diameters. For instance, with a 2-inch and a 4-inch pipe of the same length, in order to force the same quantity of water through them, the difference of loss of head would be as 1,024 : 32; or, say 165 gallons per minute had to be discharged at a distance of 400 yards, the 2-inch pipe would require 180 feet of head, while the 4-inch pipe would only require 5·625 feet of head to overcome their friction. In proportion to the relative costs of the pipes, the size of the supply pipe, and more especially the discharge-pipe should be large. An objection to hydraulic pumps arises from the fact, that whether the pump has much or little work to do it takes the same quantity of water to do it. The water after doing its work in the hydraulic pump is discharged into the delivery and returned along with that pumped to the sump.

A very ingenious method of raising water from mines is by means of Moore's hydraulic mine-pump. An ordinary horizontal steam-engine placed on the surface works a double-acting water-ram, also on the surface. A strong wrought-iron tube connects the two ends of the water-ram case, and also from either end of this case a power pipe is carried down the shaft to the bottom, or to any point in the workings where it is convenient to fix the hydraulic pump.

The hydraulic pump consists of a double-plunger pump, having connecting rods projecting through glands at each end, and these are made a suitable length to form the plungers of two hydraulic rams, placed at either end of the main pump as shown in Fig. 309. The two power pipes after being carried down the shaft are connected to the outer end of each hydraulic ram. The main pump is double acting, and has two suction valves and connections to a single pipe from the sump or cistern and also two outlet valves and connections to the rising main. Protection against shocks caused by the stoppage of the moving power column, or by irregularities between the motion of the engine rams and the underground hydraulic rams, is obtained by a connection between the two power pipes, and by providing a relief-valve, which, when opened, allows the water to pass from one column to the other. The hydraulic ram gives motion to a small bell crank at the end of each stroke, which works the relief-valve. The reciprocating action of the engine rams on the surface is transmitted direct to the underground hydraulic rams, the water forming a rod which receives motion from the engine rams at one end, and transmits it to the hydraulic rams at the other, there being no valves whatever between. The water in the power pipes should be quite clean when first placed there, and is not afterwards changed. Care must be taken, however, to maintain the column of water solid, so as to completely fill the ram cases and the power pipes; and to provide against leakages, small inlet valves and pipes, connected to a cistern, are placed at a higher level. If the pump is a small one, the steam-engine on the surface may be direct-acting; the piston rod passing out through the back cylinder cover, and there connected to the water-ram. With large pumps, a small engine running at a high speed may be geared to the pump, as the water in the power pipes must not have a high velocity. The engine should have a heavy fly-wheel on the crank shaft. The power columns are worked at a high pressure—about 1,000 lb. to the square inch. The area of the rams and power pipes should be so proportioned that the rams travel at a speed of about 80 ft. per minute, and the speed of the water in the power pipes

may be about 300 ft. per minute. The relative sizes of the plunger pump and the hydraulic rams must necessarily vary with the quantity of water and height to which it is to be raised, and also with the pressure at which it may be decided to work the hydraulic rams.

A great advantage from this system of pumping water out of mines, arises from its having no moving rods in—or beam overhanging—the pit, no leaky steam-pipes in the shaft; the only moving parts being at the engine on the surface, and at the hydraulic pump underground; and further, the power pipes take up less room in the shaft than pump rods. It is applicable to pump water in a shaft from any depth, or from dip workings which may be at a considerable distance from the shaft, or it may be used in a sinking pit. Where used to drain a sinking shaft

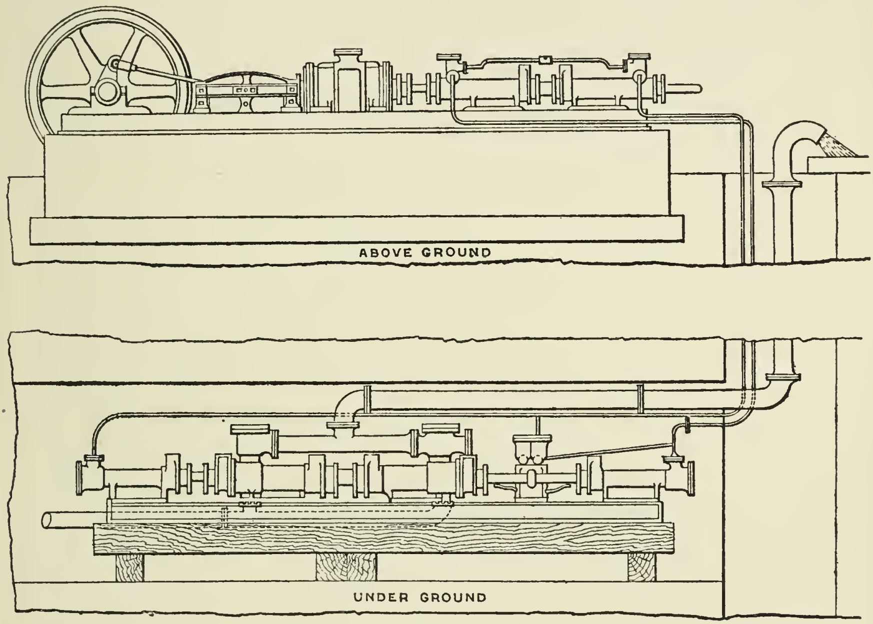


Fig. 309.—Moore's Hydraulic Mine Pump.

the pump and pipes work in guides, and are suspended by two chains or rods from a hydraulic ram fixed on the surface, and lowered as the sinking proceeds.

When a shot has to be fired in the bottom the whole apparatus is raised a few feet out of the pit bottom. The shot having been fired without injury to the pump, the latter is again lowered into its place in the sump.

A method of pumping water out of dip workings consists in making use of a hauling rope where one is at work, which may be made to give motion to the pump. For the same purpose a steam-engine may be placed at the shaft and communication made to the pump by means of a clip pulley and an endless rope. Wire-rope systems of pumping require considerable attention, are expensive to maintain, more especially where the rope is carried along undulating roads having many curves. For pumping limited quantities up from dip workings, a horse-pump and for still smaller quantities a hand-pump may be used. Pumps worked by horses, however, are not to be recommended. The net result from horses employed in this work is very small, as they can only be worked for a short period at a time.

The application of electricity to underground pumping is practical and in some instances may be economical. At the Trafalgar Colliery, Forest of Dean, Mr. Frank Brain has erected pumping plant which is working satisfactorily and economically. The plant consists of a single 16-inch cylinder engine with a 12-inch stroke working with about 35 lbs. steam pressure on the surface. The power is applied to a generator placed on the surface near the shaft, by means of a belt carried on two pulleys, one being on the crank shaft of the engine, the other on the generator. The pump and electro-motor (the latter being a machine for converting the energy of electric currents into the energy of mechanical motion) are underground at a distance of 1,650 yards from the bottom of the shafts, and the water is raised through a vertical height of 300 feet to the pit bottom, along slant roads.

The pump is a double 9-inch plunger with a 10-inch stroke and fitted with gear running six to one. The spur pinion is keyed on the same shaft as a 64-inch pulley which receives motion from a 14-inch pulley on the motor shaft by means of a leather link belt. When the motor runs 650 revolutions per minute, the pump makes 25 revolutions.

The electric current is conveyed to the motor from the generator on the surface by means of a copper cable 2,000 yards long, wrapped with compounded tape, and taken down the shaft in wooden boxes. It is not afterwards enclosed but carried along the side of the underground roads, being supported on earthenware insulators at intervals of about 10 yards. An old pit rope is used as a return cable. It is about 4 inches in circumference and secured to the road posts by staples. A small insulated copper wire, connected to a battery of eight No. 3 Leclanche cells, connects the engine-house on the surface with the pump-house underground, and through this is registered, upon a bell placed for the purpose in the former, each stroke of the pump. The same wire serves as a telephone line, so that conversation can be carried on between anyone in the engine-house with the man in charge of the pump underground. The water pumped is about 114 gallons per minute.

Syphons may be beneficially applied for conveying water in mines under certain circumstances. The principle of the syphon depends upon the fact that the atmospheric pressure will sustain a column of water 34 feet high. In its simplest form it is merely a tube bent like the letter U inverted, and having one leg longer than the other. If the short leg be inserted in the water to be drawn off and the air extracted from the inside of the tube, the atmospheric pressure acting on the surface of the liquid forces it up the tube. The liquid will consequently flow through the longer leg until the level of the liquid falls below the short end of the tube, or, if the liquid be water, until the surface falls to 34 feet below the highest point of the tube.

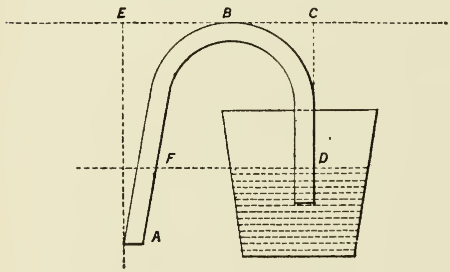


Fig. 310.—The Syphon.

Two circumstances limit the application of the syphon. Its highest point must be less than 34 feet above the surface of the water to be run off, and the delivery end of the pipe must be lower than the plane of the surface of the water to be removed. Suppose, in Fig. 310, A B D to be a syphon filled with water. The force acting on the vessel at D is the pressure of the atmosphere and the water is driven in the direction D B by that force, less the weight of a column of water whose

height is D C, and the force acting on the water at the discharge A is the pressure of the atmosphere, less the weight of a column of water whose height is A E. From this we find the pressure tending to maintain the flow of water. Suppose the long leg in the syphon to be 30 feet and the short one to be 20 feet, the pressure maintaining the flow would be as follows :—

	Pounds per square inch.	Pounds per square inch.
Pressure of the atmosphere at D	14·7	
,, ,, the water column D B, 20 ft. × 12 × ·036 =	8·64	6·06
,, ,, the atmosphere at A	14·7	
,, ,, water column A B, 30 ft. × 12 × ·036 =	12·96	1·74
		4·32

The effective pressure acting on the water towards B is 6·06 lbs. per square inch and that at A, tending to uphold the column is 1·74; so that the real effective pressure maintaining the flow is 4·32 lbs. per square inch. Any other lengths of

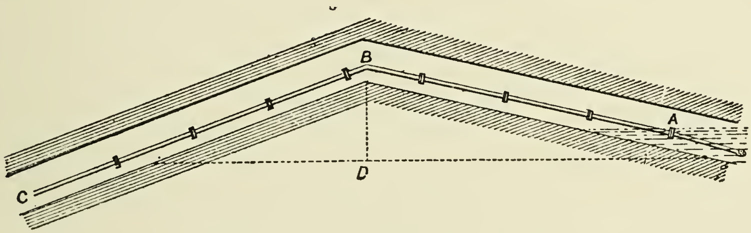


Fig. 311.—Syphon Working in a Mine.

legs may be calculated, and it will be seen that the less the resistance in the long leg, the more is the effective power increased. Fig. 311 shows the method of laying a syphon in a mine where it is desired to remove the water from the workings at A over the hill B, to C, where proper provision is made for its after disposal. The vertical height D B, should not exceed 28 or at the most 30 feet. Care should be taken in laying the pipes to make the joints perfectly air-tight. A clack must be fitted at A, to prevent a back-flow of water during the filling of the pipes. A tap must be placed at the delivery end C, which is kept shut during the filling. A small tap must be placed at the highest point B, and if the pipes have not a regular rise and fall each way from B (which should be always aimed at), a small tap or plug must be placed at every point in the pipes where they dip both ways. These are necessary for the air to pass out of the pipes as they are being filled. For this purpose these taps are opened, or if plugs they are taken out during the filling, and as the water rises in the pipes to each hole, the taps are closed or the plugs put in. When the pipes are full the tap at C is opened. There are different ways of filling the syphon. Where the syphon is near the shaft or circumstances admit of it, small pipes may lead from a cistern to the syphon, in which case it is merely necessary to turn the tap of the small pipes to fill the syphon. Another plan is to pump the water in from the supply end. A third method is by pouring water into the pipes at the highest point, but this usually entails leading the water there, and would only be adopted under exceptional circumstances.

In long syphons with pipes of large diameter, the water to be run off varying in quantity, a good plan is to sink a staple under the short leg and continue the pipe down into it, and it thus becomes self-regulating, because the water will not

sink below the level of the pipe, though the feeder may vary. In cases where the feeder is not sufficient to keep the pipes running full, a float may be placed on the top of the water, and connected with a chain passing over a fixed pulley with a weight attached. As the water lowers the weight is drawn up by the float so as to partially stop up the intake-end of the pipes, and as the water rises again the float is raised, and the weight lowered, thereby allowing the syphon to run faster. In fixing syphons it should be borne in mind that the greater the fall in the delivery-leg, and the less the height of the short or suction end, the better it will work, as has been demonstrated by the explanation accompanying Fig. 310 and the example given. Although theoretically 34 feet is the height to which the water will rise, owing to atmospheric pressure, in practice that is never attained, and a syphon must be well laid and managed where the highest point of it is 30 feet above the suction-end of the pipes. Gas oozing from the ground, and rising in bubbles through the water beneath either end of the syphon, interferes with its action in the same way as leakages at the joints, and will sometimes cause the stoppage of the syphon. To prevent this a bell-mouthed piece of metal with a bottom to it may be placed in the water below the end of the pipe where such gas is, which will divert the bubbles, and prevent their entering the pipe. A good plan consists in placing an air-receiver at the highest point in the pipes, because the water absorbs more air at atmospheric pressure than it is able to retain in absorption under the reduced pressure at the summit of the pipes. An air-pump can then be used to extract the air, a tap being placed in the receiver.

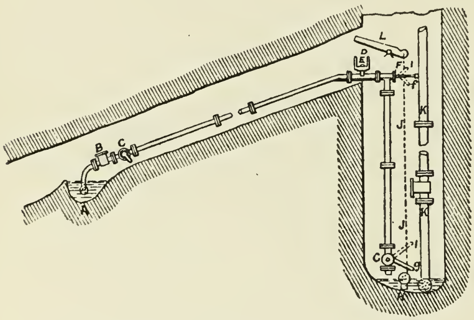


Fig. 312.—Syphon connected with Pit-pumps.

The practice of having pipes of a larger diameter at the delivery-end, as compared with the suction-end, is to be condemned. The consequence of such an arrangement is that the discharge must leave room for air to enter, which will interfere with the working of the syphon. A cure for this would be to let the delivery-pipe be taken to a box, and the discharge always be under water. The water would run over the sides of the box, and the entry of air be prevented. It is much better to lay pipes of a uniform size, or where this is not done, to let the delivery-end be the smaller pipes.

The sketch of syphon (shown at Fig. 312) is well suited for a large quantity of water, the pipes being from 3 to 6 inches diameter, made of cast-iron with flange joints. A is a suction pipe. B is a clack-valve opening outwards. C is a regulating tap which is used only when the water is nearly out or the pipes likely to come on "air." E is a T-pipe, on the top of which, but in the bottom of box, D, is an air-discharging valve ; this box should be kept full of water to prevent any air from entering by the valve when the syphon is working. F is an inch pipe, with a tap turned by lever f, which is in the position of shut as shown ; this pipe connects the syphon with K, the pit-pumps. G is a large tap, with a lever similar to f ; in this position it is shown open. H is a weight to take down the levers f and g when they are in the position of I I. J, J, is a rod which connects levers f and g together.

If the pipes are empty, and are required to work, press down the lever, L, which will raise levers f and g to the position of I, I. By this action the tap, F, is opened, and the large tap, G, is shut when the water rushes through the tap, F,

into the syphon, which fills it in a few minutes, the air blowing off at valve, E. Whenever the air is all expelled from the pipes the water overflows at box, D; then let go the lever, L, when the weight, H, will take down levers f and g, which shuts the tap, F, and opens the large tap, G; the syphon will now be working, and will do so while the pipes get water at A.

The following useful memoranda relate to water and pumps:—

From Molesworth.

1 Cubic foot of water = 62·4 lbs. = 6·2355 gallons.
1 Cubic inch of water = ·036 lbs.
1 Imperial gallon of water = 10 lbs. = 0·16 cubic foot = 277·274 cubic inches.
1 Cwt. of water = 1·8 cubic foot = 11·2 gallons.
1 Ton of water = 35·9 cubic feet = 224 gallons.

Pressure of Water per square inch at Different Heads.

P = Pressure in lbs. per square inch.
H = Head of water in feet.
$P = H \times \cdot4333.$
$H = P \times 2\cdot31.$
Pressure per square foot = $H \times 62\cdot4$.
Cubic feet of water × ·557 = Cwt. approximately.
" × ·028 = Tons "
1 Cubic foot of sea water = 64·14 lbs.
Weight of sea water = weight of fresh water × 1·028.

Delivery of Water in Pipes.

D = Diameter of pipe in inches.
H = Head of water in feet.
L = Length of pipe in feet.
W = Cubic feet of water discharged per minute.

$$W = 4\cdot72 \sqrt{\frac{D^5 H}{L}}$$

$$D = \cdot538 \sqrt[5]{\frac{L \times W^2}{H}}$$

Hawkesley's formula for the delivery of water in pipes is,
G = Number of gallons delivered per hour.
L = Length of pipe in yards.
H = Head of water in feet.
D = Diameter of pipe in inches.

$$D = \frac{1}{15} \sqrt[5]{\frac{G^2 L}{H}}$$

$$G = \sqrt{\frac{(15\,D)^5 H}{L}}$$

Molesworth's Rule for the Weight of Pipes.

D = Outside diameter of pipe in inches.
d = Inside diameter.

w = Weight of a lineal foot of pipe in lbs.

$w = k\,(D^2 - d^2)$.

and k = 2·45 for cast iron.
2·64 „ wrought iron.
2·82 „ brass.
3·03 „ copper.
3·87 „ lead.

The following are also from Molesworth:—

Useful Numbers for Pumps.

D = Diameter of pump in inches.
S = Stroke of pump in inches.
$D^2 \times S \times {\cdot}7854$ = cubic inches.
$D^2 \times S \times {\cdot}002833$ = gallons.
$D^2 \times S \times {\cdot}0004545$ = cubic feet.
$D^2 \times S \times {\cdot}02833$ = lbs. fresh water.

To find the Diameter of a Single-acting Pump.

L = Length of stroke in feet.
G = Number of gallons to be delivered per minute.
N = Number of strokes per minute.
D = Diameter of pump in inches.

$$D = \sqrt{\frac{G}{{\cdot}034 \times L \times N}}$$

$$G = D^2 \times {\cdot}034\ L\ N.$$

The reason of ·034 being used in this formula is that a cylinder 1 inch diameter and 1 foot long contains ·034 of a gallon.

Note.—This formula gives the net diameter of the pump-plunger; it is usual to increase the area of the plunger $\frac{1}{4}$th to allow for leakage, &c.

Pumping Engines.

G = Number of gallons to be raised in 24 hours.
h = Height in feet to which the water is to be raised.
H. P. = Horse-power required.

$H.\,P. = \dfrac{G \times h}{4{,}752{,}000}$. 20 per cent. must be added to overcome friction, &c., and 50 or 60 per cent. more is usually allowed for contingencies, making a total of 70 or 80 per cent. additional power.

The number 4,752,000 in this formula is merely derived from 33,000 (the number of pounds raised 1 foot high per minute per horse-power) × 24 × 60.

To find the quantity of water an engine of given horse-power will pump.

H = Horse-power of engine.
F = Depth of pit in fathoms.
G = Quantity of water in gallons per minute.

$$G = \frac{H \times 550}{F}$$

$$H = \frac{F \times G}{550}$$

The reason of 550 being used in this formula is that 33,000 lbs. raised a foot high per minute equal 1 horse-power, and there being 10 lbs. of water to one gallon, and 6 feet in a fathom, we have $\frac{33{,}000}{10 \times 6} = 550$.

The quantity of water in any pipe 3 feet long is its diameter squared and divided by 10, the result being the number of gallons.

Andre, in his treatise on *Coal Mining*, gives the following rule to find the thickness necessary for cast-iron pipes :—

$t = \cdot000144\ H\ D$, where H represents the head of water in feet, and D the diameter in inches.

Percy, in his *Mechanical Engineering of Collieries*, gives the following rule for condensing water :—

W = Weight of steam to be condensed.
T = Its temperature.
l = Its latent heat.
W' = Weight of injection-water required.
t = Its temperature.
t' = Temperature of the mixture.

Then $W' = \frac{(T + l - t')\,W}{t' - t}$, the latent heat of steam varying from 966 at atmospheric pressure to 939 at 15 lbs., and 920 at 30 lbs. above the atmosphere.

A few questions will now be given and worked out, in which some of the foregoing formulæ will be applied.

Question 68.—What is the H. P. of an engine capable of raising 560 gallons per minute from a pit 150 fathoms deep? Give the diameter of the working barrel, and state what velocity the water should travel at.

The diameter of the working barrel must depend upon the length of stroke at which the engine works, and upon the number of strokes per minute at which it is driven. As per the question the quantity of water is large assume that we adopt a Cornish single-acting beam-engine to raise the water, working with a 10-foot stroke, and being driven at 5 strokes a minute, at which it may comfortably work, the pumps being single acting. Then $\sqrt{\frac{560}{\cdot034 \times 10 \times 5}} = 18\cdot15$ inches as the net diameter of pumps, but adding $\frac{1}{4}$th to the area to allow for leakages, we have $18\cdot15^2 \times \cdot7854 = 258\cdot72$, the area, and $258\cdot72 + \frac{258\cdot72}{4} = 323\cdot4$, and a working barrel whose area is $323\cdot4$ would have a diameter of $\sqrt{\frac{323\cdot4}{\cdot7854}} = 20\cdot29$, or say, 20 inches as the diameter of the working barrel.

The velocity of the water in the pipes should not exceed 240 feet per minute, and it will be better to limit it to 200 feet per minute. In the above arrangement the flow of water in the pumps would be 50 feet per minute, which is much within the required limits. To find the horse-power of the pumping-engine remember that 1 H. P. is represented by the raising of 33,000 lbs. 1 foot high in a minute. In this case, since there are 10 lbs. to the gallon, and 6 feet to the fathom, there are to raise $560 \times 10 = 5{,}600$ lbs. through a vertical height of $150 \times 6 = 900$ feet in one minute, and therefore it would require $\frac{5{,}600 \times 900}{33{,}000}$ or $\frac{560 \times 10 \times 150 \times 6}{33{,}000} = 152\cdot7$ H. P., but to this must be added 80 per cent., 20 per cent. to overcome friction, and 60 per cent. for contingencies. Therefore, $152\cdot7 + \frac{152\cdot7 \times 80}{100} = 275$ nearly, which is the horse-power of the engine required.

Question 69.—What size of pumping-engine would you erect underground to raise 30,000 gallons of water per hour from a depth of 300 yards?

Assuming that the piston and pump are double-acting, and that the piston will work at 250 feet per minute, which is a safe speed, and have an effective steam-pressure of 30 lbs. per square inch $\frac{30{,}000}{60} = 500$ gallons per minute, and as the pump works at 250 feet per minute, $\frac{500}{250} = 2$ gallons for each foot the pump works. $2 \times 277{\cdot}274 = 554{\cdot}548$ cubic inches in each foot of the pump. $\frac{554{\cdot}548}{12} = 46{\cdot}212$ square inches area, allow say $12{\cdot}788$ square inches for the pump-rod of about 4 inches diameter $= 59$ and $\sqrt{\frac{59}{{\cdot}7854}} = 8{\cdot}667$; say, to allow for leakages 10 inches as the diameter of pumps necessary. The pressure per square inch of water on a 300-yard column will be $300 \times 3 \times {\cdot}4333 = 390$ lbs. and $46 \times 390 = 17{,}940$ lbs. total pressure on the pump. $17{,}940 \div 30$ lbs. the steam pressure $= 598$ square inches, and adding $\frac{1}{2}$ for frictional allowances, $598 + 299 = 897$ square inches area, and $\sqrt{\frac{897}{{\cdot}7854}} = 33{\cdot}8$ inches diameter of the cylinder required for the pumping-engine; the stroke might be made 6 feet, and it would then work $\frac{250}{6 \times 2} = 20\frac{5}{6}$ revolutions per minute. The stroke of the pump should always be made as long as practical considerations will admit of.

Question 70.—What quantity of water could you raise and from what depth with an Underground Pumping-Engine, having a 30-inch cylinder and 5-foot stroke, double acting, working a 12-inch pump also double acting, the effective steam pressure on the piston being 30 lbs?

Assume a piston speed of 250 feet per minute, or $\frac{250}{5 \times 2} = 25$ revolutions per minute. The pump-rod will be the same size as the piston-rod, and the piston-rod would be about $\frac{1}{8}$th the diameter of the piston, or $\frac{30}{8}$ = say 4 inches or $12\frac{1}{2}$ square inches area. Deduct this from the area of the pump, thus $(12^2 \times {\cdot}7854) - 12\frac{1}{2} = 100{\cdot}5$ as the effective area. The 30-inch cylinder has an area of $706{\cdot}86$, from which deduct the third for frictional allowances $= 706{\cdot}86 - 235{\cdot}62 = 471{\cdot}24$ say 471 square inches area on which the steam pressure operates; $471 \times 30 = 14{,}130$ available effective power. The effective area of pump being $100{\cdot}5$, $\frac{14{,}130}{100{\cdot}5} = 140{\cdot}5$ lbs. pressure which the pump can support and $\frac{140{\cdot}5}{{\cdot}4333} = 324$ feet height of column. And to find the quantity $100{\cdot}5 \times 12 = 1{,}206$ cubic inches in each foot $\frac{1{,}206}{277{\cdot}274} = 4{\cdot}4$ gallons per foot. $4{\cdot}4 \times 250 = 1{,}100$ gallons per minute. $1{,}100 \times 60 = 66{,}000$ gallons per hour, the quantity of water this engine would raise to a height of 324 feet.

In working out these two examples the method given by Mr. Percy, in his *Mechanical Engineering of Collieries*, has been adopted.

Question 71.—The feeders of water at a Colliery are lifted at the rate of 3,000 tons in 12 hours by an engine going 12 strokes per minute, length of stroke 5 feet 6 inches. What diameter of pump will be required, and what is the feeder per minute in gallons?

To find the feeder per minute, which is dealing with the last part of the question first, 3,000 × 224 (the number of gallons in a ton) = 672,000 the number of gallons lifted in 12 hours, therefore $\frac{672{,}000}{12 \times 60} = 933 \cdot \dot{3}$ gallons per minute, which is the feeder. Assuming the pumps to be single-acting and adopting Molesworth's rule as already given, $D = \sqrt{\frac{933 \cdot \dot{3}}{\cdot 034 \times 5 \cdot 5 \times 12}} = 20 \cdot 4$; or the same result may be arrived at as follows, $D = \sqrt{\frac{933 \cdot \dot{3} \times 277 \cdot 274}{5 \cdot 5 \times 12 \times 12 \times \cdot 7854}} = 20 \cdot 4$ as before (277·274 being the number of cubic inches in a gallon). This gives the net diameter of the pump plunger, and it is usual to increase the area of the plunger $\frac{1}{4}$th to allow for leakage, &c. Therefore $20 \cdot 4^2 \times \cdot 7854 = 326 \cdot 74$ area of plunger and $326 \cdot 74 + \frac{326 \cdot 74}{4} = 408 \cdot 4$ which is the area the pumps should be and $\sqrt{\frac{408 \cdot 4}{\cdot 7854}} =$ 22·804 or say 23 inches, which is the diameter the plunger should be to pump 3,000 tons of water in 12 hours by an engine going 12 strokes per minute with a 66-inch stroke.

Question 72.—Describe the general arrangements, diameter of cylinder, length of stroke of pump, and pressure of steam by which 2,000 tons of water may be raised from a depth of 200 fathoms in 24 hours.

$\frac{2{,}000 \times 224}{24 \times 60} = 311$ gallons to be pumped per minute, but this would allow no margin for the engine to rest through accident, and as the depth is great, entailing many working parts, it would not be prudent to assume that the engine can go on continuously, and the colliery may have no storage arrangements. Assume that the engine work 16 hours out of the 24, then $\frac{2{,}000 \times 224}{16 \times 60} = 467$ gallons to be pumped per minute. It would be better to choose an engine placed on the surface to deal with this water, because it would be necessary to use large pumps of 18 or 19 inches diameter. If an engine were placed underground and one column of pumps used, the thickness of metal in the bottom part of the column would be excessive. For 19-inch pumps in a 200-fathom pit, it must be $\cdot 000144 \times 200 \times 6 \times 19 = 3 \cdot 283$ inches, a thickness of metal for pumps never adopted and not practicable, and even for a 12-inch set it would require to be over 2 inches, a size not often exceeded for pumps.

The most approved engine to do the work would be Davey's Compound Differential Pumping Engine, but, assuming that a Cornish single-acting engine with beam overhead be adopted and that it works with a 10-foot stroke, it may be driven comfortably and steadily at 5 strokes a minute. To find the size of pumps then $\sqrt{\frac{467 \times 277 \cdot 274}{10 \times 12 \times 5 \times \cdot 7854}} = 16 \cdot 57$ diameter, or allowing $\frac{1}{4}$th increase of area for leakage, it means 18·57, or say 19 inches as the diameter of the working barrel and plungers. In arranging the sets in the shaft divide them into 5 sets of 40 fathoms each, and for reasons already given, the bottom one should be a lifting set, the others being all forcing sets.

To find the horse-power of the engine assuming that there is an effective steam pressure on the piston of 30lbs. $\frac{467 \times 10 \times 200 \times 6}{33{,}000} = 169 \cdot 82$ or say 170 horse-power, but to which must be added 80 per cent., 20 per cent. to overcome friction and 60 per cent. more for contingencies $170 + \frac{170 \times 80}{100} = 306$ as the horse-power of

the engine; and to find the diameter of the cylinder $\frac{306 \times 33{,}000}{10 \times 5 \times 30 \text{ (press. of steam)}}$ $= 6{,}732$ the area of the piston in inches and $\sqrt{\frac{6{,}732}{\cdot 7854}} = 92{\cdot}58$ or say 93 inches as the diameter of the piston, for the Cornish Beam Pumping-engine to do the required work.

Question 73.—How many gallons are there in 1,200 tons of water? Describe the general arrangement and size of pumps for lifting that quantity daily from a pit 80 fathoms deep.

$1{,}200 \times 224 = 268{,}800$ gallons. If the pumping-engine were placed on the surface, the general arrangement would be to divide the 80 fathoms into two, and have a lifting set of 40 fathoms at the bottom, and a forcing set at the top, or a short lifting set of 10 or 15 fathoms might be fixed at the bottom, and the remaining height of 70 or 65 fathoms divided into two even divisions for two forcing sets above. The pumps would be single-acting, and to find their diameter, $\frac{268{,}800}{24 \times 60} = 186{\cdot}\dot{6}$ gallons per minute to be pumped. Assuming the engine to have a 10-foot stroke and to work 5 strokes a minute $\sqrt{\frac{186{\cdot}\dot{6}}{\cdot 034 \times 10 \times 5}}$ $= 10\frac{1}{2}$, to which add $\frac{1}{4}$th to the area, or say 12 inches as the diameter of pumps, if the engine worked continuously.

Question 74.—Describe the class of engine best adapted for the above work, size of cylinder, length of stroke and strokes per minute.

It would be better to use an underground pumping-engine, if there were no danger of its being drowned. The Differential Engine might be applied, or a Worthington steam pump, which would be double-acting as would the engine, and the engine should be condensing. Taking a piston speed of 250 feet per minute, and an effective steam-pressure of 30lbs, then $\frac{187}{250} = \cdot 75$ of a gallon for each foot the pump works. $\cdot 75 \times 277{\cdot}274 = 208$ cubic inches in each foot of the pump, $\frac{208}{12} = 17{\cdot}\dot{3}$ square inches area, say the pump-rod is 2 inches in diameter = 3 inches area, and deduct 3 from $17{\cdot}\dot{3} = 14{\cdot}\dot{3}$, and $\sqrt{\frac{14{\cdot}\dot{3}}{\cdot 7854}} = 4{\cdot}27$ inches diameter of pump, and to allow for leakage make them 6 inches. The pressure per square inch of water on an 80-fathom column will be $80 \times 6 \times \cdot 4333 = 208$, and $17{\cdot}\dot{3} \times 208 = 3{,}598$ lbs. total pressure on the pump $\frac{3{,}598}{30 \text{ (steam press.)}} = 120$ square inches, and adding $\frac{1}{2}$ for friction $120 + 60 = 180$ square inches area, and $\sqrt{\frac{180}{\cdot 7854}} = 15\frac{1}{8}$ as the diameter of the cylinder in inches, the stroke might be made 3 feet, and it would then work $\frac{250}{3 \times 2} = 41\frac{2}{3}$ revolutions per minute.

Question 75.—State the advantages in a deep shaft of having a series of lifts instead of one long lift to the surface.

It is not practicable to have unduly long lifts of pumps; they are limited by the strength of material required. If it was contemplated to put one long lift in a deep pit, on an estimate being made of the thickness needed for the pipes and

the size of the spears it would be found impracticable to adopt that plan. Great wear would result to a bucket of one long lift, requiring constant changing and repairing; broken spears, especially near the bottom of the lift, would be a source of great annoyance and expense, and the arrangement would not give facility for counterbalancing the engine.

Question 76.—A pumping-engine goes 14 strokes per minute for 13 hours a day, working two 18-inch sets with a 49-inch stroke. What is the feeder per minute?

$\frac{18^2 \times \cdot 7854 \times 49}{277 \cdot 274} = 45$ gallons per stroke for each set, 90 gallons per stroke for the two, and $90 \times 14 = 1{,}260$ gallons as the feeder pumped per minute; but from the question it would appear that this quantity pumped per minute for 13 hours represents what is made in the pit during the 24 hours, and if so the feeder in the pit would be $\frac{1{,}260 \times 60 \times 13}{24 \times 60} = 683$ gallons per minute.

Question 77.—Describe the pulsometer.

The following description of the pulsometer is taken partly from the *Colliery Guardian* of Sept. 29th, 1876, and partly supplied by the Pulsometer Engineering Co., Nine Elms Ironworks, London.

This pump may be said to raise water by the direct pressure of steam upon its surface, and then to turn this same steam to account in forming the vacuum necessary for effecting the suction for the next lift. This is accomplished without the intervention of any piston or plunger. The invention is, in fact, but a perfection of the principle of Thomas Savery in 1698, and by him carried out so clumsily that the idea seems to have been abandoned until now; and engineers have been content in the meantime to interpose between the power and its work a complicated set of working parts, adding greatly to the first cost of the pump, introducing a heavy item for repairs and maintenance, and diminishing the duty on account of friction.

The pulsometer as now constructed, consists of a hollow casting, called the body, composed of two pear-shaped water-chambers, with their necks joining above, between which is the air-vessel, while the discharge chamber is a kind of offshoot from the lower portion of the body. The steam admission-valve is bolted on at the top, at the junction of the ends of the water-chambers; and the suction pipe is similarly bolted on at the bottom. The construction will, however, be better understood on reference to the drawing, Fig. 313, which is a vertical section through the pulsometer. A A are the two water-chambers surmounted by a separate casting containing the steam ball-valve I, fitted so as to pass alternately between the seats formed in the junction, and connected at top with the steam pipe K. The water-chambers terminate at bottom in a suction-chamber, to which the suction pipe is bolted, while the suction valves E E, with their seats, are arranged at an angle of 45 degrees between them. Covers for closing the spaces are left in the casting for the insertion of the valves, and also for the removal of any obstructions. The air-vessel for rendering the flow constant, is situate between the necks of the water chambers, and is in direct communication with the suction.

A discharge chamber common to the two water-chambers A A, and leading to the discharge pipe D, is provided, and this contains one or two valves, according to the purpose to be fulfilled by the pump, which are shown in dotted lines in the figure. Small air-cocks are screwed into the cylinders and air-chamber, for use as described hereafter.

The pump being filled with water, either by pouring water through the plug hole in the chamber, or by drawing the charge, according to the printed directions, is ready for work. Steam being admitted by slightly opening the stop-valve which allows it to enter the steam-pipe K, it passes down that side of the steam neck which is left open to it by the position of the steam ball, and presses upon the small surface of water in the chamber which is exposed to it, depressing it without any agitation, and consequently, with but very slight condensation, and driving it through the discharge opening and valve into the rising-main.

The moment that the level of the water is as low as the horizontal orifice which leads to the discharge, the steam blows through with a certain amount of violence, and being brought into intimate contact with the water in the pipes leading to the discharge chamber, an instantaneous condensation takes place, and a vacuum is in consequence so rapidly formed in the just emptied chamber, that the steam ball is pulled over into the seat opposite to that which it had occupied during the emptying of the chamber, closing its upper orifice and preventing the further admission of steam, thus allowing the vacuum to be completed; water rushes in immediately through the suction pipe, lifting the inlet valve E, and rapidly filling the chamber A again. Matters are now in exactly the same state in the second chamber as they were at the commencement in the first chamber, and the same results ensue. The change is so rapid that, even without an air vessel on the delivery, but little pause is visible in the flow of water, and the stream is, under favourable circumstances, very nearly continuous. The air-cocks are introduced to prevent the too rapid filling of the chambers on low lifts, and for other purposes, and a very little practice will enable any unskilled workman or boy so to set them by the small nut that the best results may be obtained. The action of the steam ball is certain, and no matter how long the pump may have been standing, it will start as soon as dry steam is admitted.

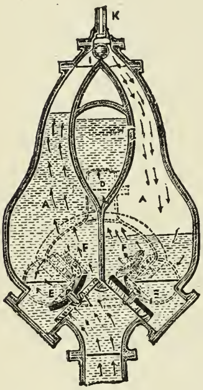


Fig. 313.—The Pulsometer.

The smallness of the quantity of steam used in raising the water and effecting the condensation, is proved by the very slight increase of temperature acquired by the water raised.

It will be noticed that great simplicity of form and fewness of working parts are attained in the pulsometer; there are, in fact, only 5 moving parts, the steam-admission valve, the two suction or foot valves, and the two delivery valves. These, again, are made as simple and efficient as possible. The steam-ball valve, when once made spherical, wears itself and its seats true, as it turns in its bed at every pulsation. The foot and delivery valves may be of the same character, though larger, with suitable guards, but for heavy work the flap-valve is found preferable. It consists of a cast-metal shoe, planed on its lower surface, and having a bored recess into which is fitted a seat made of hard wood boiled in oil, the end of the grain being the part exposed to wear. This surface is turned true, and the wood is fastened in the shoe by a bevelled brass ring secured with pins. The flap works in a bored bearing, and is kept in its place by a guard cast on the cover of the chamber, or by a small cover. Its play is regulated by a stop on the chamber cover, and noise is prevented by the wood lining of the horn of the valve. In some instances the flap valves are furnished with wooden faces. India-rubber is also used for some purposes, either in the form of a flat disc or the hollow valve designed by Perreaux.

In the majority of pumps, grid valves are employed as shown at Fig. 313.

This is a type that has proved itself most convenient for general work, both on account of its original simplicity and durability and also of the facility it offers for repairs, it being but a matter of a few minutes for an unskilled labourer to take off the nut and guard, and to put on a fresh rubber. These grids are of brass as well as the spindle and nut, and are secured by bolts properly pitched round the circumference.

The ball valves, used instead of the clack or grid valves, are not advisable in pumps above the No. 3 or 4 size. They are made (1) all iron with iron seats; (2) gun-metal with phosphor bronze seats; (3) rubber balls with iron cores and gun-metal or iron seats.

As there are no cylinders, plungers, or complicated internal parts, but only the steam valve, and the suction and delivery valves of large area, this pump is very suitable for pumping water mixed with grit which would choke or wear out other pumps. Again, as it requires no fixing, but may be hung on a rope or

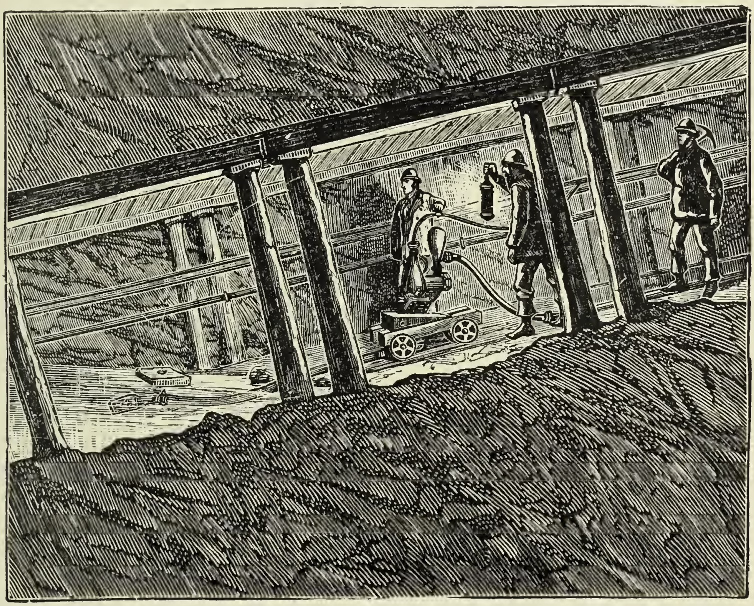


Fig. 314.—The Pulsometer Working in a Mine.

chain and may be raised or lowered by a pair of blocks, it is well fitted for sinking pits. All that is required is to provide a boiler at a reasonable distance and lead the steam through a flexible hose or through a telescopic copper steam pipe. The suction may be either of jointed cast-iron pipes terminating in a windbore, or consist of a flexible tube; the delivery pipe may also be flexible or have length after length added as the pulsometer goes down. The great feature is that when once the pump is started and the air valves adjusted, it may be left to itself, and will continue to work as long as it is kept supplied with steam.

The pulsometer will pump water, and many other liquids and semi-liquids, to a total height of from 70 to 80 feet, or under special circumstances to much greater heights. The sizes (1) and (2) are best adapted to a suction not exceeding 6 to 10 feet; the sizes (3) and (4) to a suction not exceeding 8 to 12 feet; sizes 5 and upwards to a suction not exceeding 10 to 15 feet. Each size is adapted

to a vertical discharge of from 60 to 70 feet. These figures are given as a guide, but may be modified by circumstances. The length of horizontal suction and discharge is not very material if sufficient size of pipe be employed to obviate the friction.

The steam pressure at the pump for lifts from 20 to 40 feet should not be less than from 20 to 30 lbs. per square inch, and for lifts from 40 to 80 feet not less than from 30 to 50 lbs.; for higher lifts greater steam pressure is necessary. For low lifts the pulsometer can be worked with exhaust steam.

The Pulsometer may render most useful service in draining the underground workings of water, of a very dirty or gritty nature, as shown in Fig. 314. For this purpose it is mounted on a frame running on wheels to suit the gauge of roadway. The steam-pipe is laid from the boilers to it, which may be at the surface. The discharge pipe is taken to the pit sump, or if that be at too great a vertical height, to an intermediate lodge-room or into the suction pipe of an upper pulsometer from which it is afterwards pumped on. The absence of exhaust steam, and the regularity of its working without constant attention, are strong recommendations to its use.

In the simple pulsometer it is impossible to obtain an expansive action of the steam, because the upper valve, whether a ball or other contrivance, must, from its construction, be allowing steam to pass into one or other chamber during the whole time the pump is at work. Where the work is constant, and there is a good margin between the pressure of steam and the pressure of water in the column, pulsometers (more particularly those above No. 4 size) may have the "Grel" automatic cut-off arrangement, which is patented by the Pulsometer Engineering Company. An economy of from 40 to 50 per cent. of the total steam consumption is said to be effected by this arrangement, which depends on the employment of a secondary cut-off valve, in addition to the distributing valve, so that a long interval may intervene between each pulsation, during which no steam can pass through the steam-pipe, although the work of pumping is going on continuously.

Question 78.—Suppose a sinking pit to be 200 yards deep and a barrel in the form of a frustum of cone, whose inner dimensions are $4\frac{1}{2}$ feet deep, 42 inches diameter at bottom, and 51 inches diameter at top, making its ascent and descent every 60 seconds, coming up full every time; what quantity of water in imperial gallons and in tons will be drawn in 24 hours? And, further, supposing another barrel, whose inner dimensions are 6·75 feet deep, 57 inches diameter at bottom and 45 inches diameter at top, making the same descents in the same time, the pit being the same depth as the one above described; what quantity of water would be drawn in one week from the pit in imperial gallons and tons?

Let D = diameter of water-barrel at top in feet.
,, d = ,, ,, ,, bottom, in feet.
,, h = height ,, ,, in feet.
,, c = capacity ,, ,, in cubic feet.

$$\text{Then } c = \left\{ (D^2+d^2) + (D.d) \right\} h \times \cdot 2618 \quad (1)$$

if we denote the capacity of the barrel in imperial gallons by "g" then $g = 6{\cdot}24 \times c$. Hence is obtained

$$g = \left\{ (D^2 + d^2) + (D.d) \right\} h \times 1{\cdot}632 \quad (2)$$

Again, to find the weight of water contained in the barrel, let "w" denote the weight in cwts.; then

$$w = \left\{ (D^2 + d^2) + (D.d) \right\} h \times \cdot 14571 \quad (3)$$

Applying (2)

$$g = \left\{ (4{\cdot}25^2 + 3{\cdot}5^2) + (4{\cdot}25 \times 3{\cdot}5) \right\} 4{\cdot}5 \times 1{\cdot}632 = 331{\cdot}85$$

As the capacity of the barrel is 331·85 gallons there would be wound in 24 hours, $331 \cdot 85 \times 24 \times 60 = 477{,}864$ gallons, or expressed in tons $\frac{477{,}864}{224} = 2{,}133 \cdot 32$ tons, which might have been found by formula (3). Applying (2) to the second example

$g = \{(3 \cdot 75^2 + 4 \cdot 75^2) + (3 \cdot 75 \times 4 \cdot 75)\}\ 6 \cdot 75 \times 1 \cdot 632 = 599 \cdot 68$ gallons as the capacity of the barrel: therefore, in a week of 6 days there would be hauled $599 \cdot 68 \times 24 \times 60 \times 6 = 5{,}181{,}235 \cdot 2$ gallons or expressed in tons $\frac{5{,}181{,}235 \cdot 2}{224} = 23{,}130 \cdot 5$ tons, or the same result may be got by applying formula (3).

Question 79.—The water in a pit is hauled up the shaft 350 yards deep in two tanks each holding 350 gallons, one ascending, the other descending; what horse-power is the engine which delivers a tank of water every three minutes at the surface not including the time of stoppage?

The speed of the load is 350 feet per minute and its weight $350 \times 10 = 3{,}500$ lbs. $\therefore \frac{350 \times 3{,}500}{33{,}000} = 37 \cdot \dot{1}\dot{2}$ effective horse-power according to the work done, and assuming the engine yields 50 per cent. of effective work the horse-power of the engine would be as $50 : 100 :: 37 \cdot \dot{1}\dot{2} : 74 \cdot 24$ or 74·24 horse-power.

Question 80.—What are the special advantages and disadvantages of steam pumping-engines placed underground?

The principal advantages are,—a great saving of cost and maintenance, less room is taken up in the shaft, simplicity in construction, and an equal flow of water in the pipes. The disadvantages are, danger of flooding arising from a breakdown of the engine and access to it thus prevented, and it is not suitable for depths below 150 or 160 fathoms.

Question 81.—Upon what principle does the action of the lifting pump depend, and which is the proper position for the bucket to be placed in?

The action of the pump depends upon atmospheric pressure which is equal to the weight of a perpendicular column of water 34 feet high. On the bucket being drawn up in the working barrel its tendency is to form a vacuum beneath it. But the atmospheric pressure causes the water to fill such vacuum and follow the bucket for a distance not exceeding 34 feet. In practice the bucket must never be raised more than 32 feet above the surface of the water, the usual distance from the windbore to the bottom of the working barrel is from 9 to 12 feet, and lifting or forcing pumps are arranged so that the suction shall not exceed 20 feet in height. This allows a bucket having a 12-foot stroke (which is not often exceeded) to be as effective at the top of its stroke as at the bottom when it is close to the suction pipes.

CHAPTER X.

THE GASES MET WITH IN MINES: VENTILATION.

The Atmosphere—Specific Gravity—The Symbols of Gases—Atomic Weight—Oxygen—Nitrogen—Carbonic Acid, or Carbonic Anhydride—Carbonic Oxide—Sulphuretted Hydrogen or Hydrogen Sulphide—Proto-carburetted Hydrogen—Blowers—Outbursts—Pressure of Firedamp in the Solid Coal—Effect of Earthquakes in Liberating Gas—Afterdamp—Explosions of Firedamp—The Diffusion of Gases—Natural Ventilation—The Furnace—The Waterfall—The Steam Jet—The Struvé Ventilator—Nixon's Ventilator—The Fabry Ventilator—The Lemielle Ventilator—Cook's Ventilator—Root's Ventilator—Guibal Fan—Waddle Fan—The Schiele Fan—The Capell Fan—The Medium Fan—Fan Arrangement for a Winding Shaft—Two Separate Engines to Drive Fan—Duplicate Fan and Engine—Ascensional Ventilation—Stoppings to Direct the Underground Air-currents—Advantages of Air-splitting—Regulators—Doors on Travelling Roads—Air-crossings—Brattice—Velocities of Air-currents in the Roads and Shafts—Relative Sizes of Downcast and Upcast Shafts—Anemometer and Measuring the Volumes of Air—Thermometer—Barometer—Effect of Diminished Atmospheric Pressure in Seams yielding Firedamp—Barometric Rules—Water-gauge—Motive Column and Rule to ascertain it—Horse-power of Ventilation—Useful Effect of Ventilating Fans—Theoretical Quantities of Air displaced by Fans—Rules for Total Volumes of Air required at Collieries.

THE atmosphere which surrounds our globe is a mixture of certain gases, chiefly oxygen and nitrogen; these gases are not chemically combined, but are merely a mechanical mixture, nevertheless the atmosphere is exceedingly uniform in constitution.

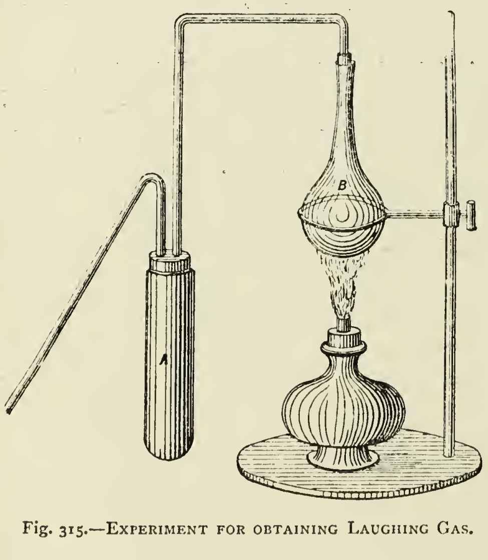


Fig. 315.—EXPERIMENT FOR OBTAINING LAUGHING GAS.

A chemical combination occurs when two substances unite to form something distinctly new in character. This is not the case with atmospheric air, for, as will be shown later, after the oxygen has been eliminated from it by means of phosphorus, the nitrogen left is not affected by the operation.

The same two gases, viz., oxygen and nitrogen, may be made to combine *chemically*, and as a result the product is totally different from either. Fig. 315 shows this. The flask B contains a small portion of the white salt known as nitrate of ammonia, which is a combination of nitrogen, oxygen, and hydrogen in certain proportions. On applying heat the hydrogen and part of the oxygen combine to form water which runs into the test-tube A. The remainder of the oxygen combines with the nitrogen and passes off as gas to the pneumatic

trough. This is nitrous oxide or laughing-gas, as it is commonly called. It is largely used by dentists and in minor surgical operations as a safe and convenient anæsthetic. So that while a mechanical union of two elements supplies the air we breathe, a chemical union of the same elements produces an intoxicating gas, which unless used with discretion is an actual poison.

The mixture forming air consists almost entirely of the two gases, oxygen and nitrogen, in the proportion of about 4 volumes of nitrogen to 1 of oxygen, the chief use of the nitrogen being to dilute the oxygen. The composition of air is—

	By Volume.	By Weight.
Oxygen .	20·93	23·141
Nitrogen .	79·07	76·859
	100·00	100·000

but it slightly varies in composition; still it is usual to consider the proportion of oxygen as $\frac{1}{5}$th and that of nitrogen as $\frac{4}{5}$ths of the volume of the air. Besides these two gases, watery vapour and carbonic acid gas form part of the atmosphere, the former being a very variable quantity, dependent upon temperature, so that it is influenced by season, latitude, &c.; the latter is generally present in the proportion of $\frac{4}{10000}$ of the whole volume of the atmosphere. Very minute quantities of ammonia and nitric acid are present in the atmosphere, as well as traces of light carburetted hydrogen and the different volatile compounds which are evolved at the earth's surface, and in towns traces of sulphuretted hydrogen and sulphurous acid also.

A proof of the fact that air is not a chemical compound lies in the fact that if 4 volumes of nitrogen and 1 of oxygen be mixed, there will be as a result 5 volumes of air without any alteration in temperature. In all cases where chemical combination takes place, there is as a result either an alteration in volume or temperature, or both. It is the oxygen of the air that supports the respiration of animals. The height of the atmosphere is about 45 miles, that is, our globe is enclosed by a covering of air which is uniformly 45 miles thick. Some authorities take it at 50 miles and some maintain that even that is not the limit; the point is therefore not definitely defined and it is not a material one to consider here. The *density* of the air diminishes as we recede from the earth, the lower strata being compressed by those above them, so that they contain within the same volume a much greater weight of air. The air is not warmed by the passage of the sun's rays through it, but when the rays reach the ground they are absorbed and raise its temperature, and this heat is radiated into the lower strata of air resting on the earth. The specific gravity of air, taken as 1 or 1,000, is employed as a standard of comparison for the specific gravities of gases and vapours. It is 815 times lighter than water and 11,000 times lighter than mercury. Its pressure at the level of the sea is equal in amount to 14·73 pounds on each square inch, or to the weight of a column of mercury 30 inches high, or one of water nearly 34 feet high. This pressure varies even at the same levels and the *barometer* is used to measure these variations. A cubic inch of mercury weighs ·491 lb., from which we get $30 \times {\cdot}491 = 14{\cdot}73$ lbs., the atmospheric pressure.

There is no difference in the composition of the air in one part of the world as compared with another, nor in that obtained from the greatest elevations reached by balloons compared with the lowest valley.

Air is an *elastic* body. If it or any gas (as they have the same physical properties) be confined in a vessel, it exerts a pressure against the sides altogether apart from its weight, and the pressure is exerted on the upper part of the vessel as well as the lower. If the volume occupied by it be in any way diminished,

that is, if the same quantity is made to occupy a smaller space, the pressure will be increased, or if the space occupied remain the same, and the temperature be raised, the pressure will also be increased.

Air is *compressible.* Boyle and Mariotte's law of compression is:—The temperature remaining the same, the volume of a given quantity of gas varies inversely as the pressure which it bears. The law showing the relation between the temperature and the volume of any gas was discovered by Charles and may be stated as follows:—If any gas be allowed to expand freely under a constant pressure, its increase of volume when raised from 32° F. to 212° F. will be equal to 0·366 of its original volume, and this law of increase holds true in the same proportion for intermediate temperatures. From this it follows that as the difference between 212 and 32 is 180, then $\frac{1}{180}$th of ·366 or about $\frac{1}{492}$, (strictly $\frac{1}{491 \cdot 8}$ or $\cdot 0020\dot{3}$) is the expansion for each degree, and this fraction is taken as the co-efficient of expansion. In other words a gas expands $\frac{1}{492}$ of its volume at 32°, or $\frac{1}{460}$ of its volume at 0° for each degree that it is raised above that point. Supposing such a question as the following be given:—A quantity of gas is measured at a temperature of 70° and is found to occupy 400 cubic inches, what is its volume at 60°? To find the proportion between the space a gas occupies at 60° and 70° of Fahrenheit's thermometer, 492 cubic inches at 32° occupy 520 at 60° and 530 at 70°. The volumes therefore for any other quantity must be in this proportion, and therefore 400 cubic inches at 70° will occupy a volume at 60° in proportion as 530 is to 520. As 530 : 520 : : 400 : 392·4 cubic inches; or say that $1 + \frac{70 - 60}{460 + 60}$ of the volume at 60° = 400 at 70°, and therefore $400 \div 1\frac{10}{520} = 392 \cdot 4$. But this is assuming the pressure to be the same in each case; if not, a correction must be made for it. For instance, if in the above example the barometer stood at 30 inches when the 400 cubic inches of gas were at a temperature of 70° but at 29 inches when at 60°, the correction for the difference in pressure would be made thus:—As 29 : 30 : : 392·4 : 406; or it may be expressed thus, $400 \times \frac{30 \times (60 + 460)}{29 \times (70 + 460)} = 406$. Or, expressing these rules as formulæ; if v be the volume of any given weight of elastic fluid under any pressure and at 32° F., the volume v_1 which it will occupy under the same pressure and at any other temperature t of F. will be $v_1 = v + v \times \cdot 0020\dot{3}\ (t - 32)$.

This will be true if the ratio of the relative volumes be put u and u_1 instead of the ratio of the absolute volumes v and v_1, thus: $\frac{u}{u_1} = \frac{1 + \cdot 0020\dot{3}\ (t - 32)}{1 + \cdot 0020\dot{3}\ (t_1 - 32)}$

Applying this to the question given,

$$\frac{u}{400} = \frac{1 + \cdot 0020\dot{3}\ (60 - 32)}{1 + \cdot 0020\dot{3}\ (70 - 32)} \therefore \frac{u}{400} = \cdot 9814,$$

and $u = \cdot 9814 \times 400 = 392 \cdot 5$.

The formula to find the relative volumes when both temperature and pressure change at the same time is:

$$u = 1 \times \frac{p_1}{p} \times \frac{1 + \cdot 0020\dot{3}\ (t - 32)}{1 + \cdot 0020\dot{3}\ (t_1 - 32)},$$ and applying this to the question in its second form,

$$u = 400 \times \frac{30}{29} \times \frac{1 + \cdot 0020\dot{3}\ (60 - 32)}{1 + \cdot 0020\dot{3}\ (70 - 32)}$$

$$u = 413 \cdot 8 \times \cdot 9814 = 406.$$

When the atmosphere is charged with moisture the mercury falls, because the pressure on the exposed surface is reduced. At first, to the student who remembers that water is about 815 times heavier than air, it will appear strange that air saturated with moisture should weigh less than air in a dry state.

Dry air is heavier than air impregnated with vapours, because of the extreme

tenuity or thinness of watery vapour, the density of which is less than that of atmospheric air, whereas the density of water is much more. The average amount of water held in suspension in 1,000 cubic feet of air is reckoned at about two-fifths of a pint. When there is as much watery vapour present as the air can contain at the existing temperature, the air is said to be *saturated.* A thousand cubic feet of air are capable of holding half-a-pint of water, and this may be regarded as the point of saturation, which, however, necessarily varies with the temperature of the air. If the temperature of air in this condition be raised a few degrees, the air is not then saturated, because the quantity of moisture necessary to produce a state of saturation is greater as the temperature of the air is increased; but if, on the other hand, the temperature slightly falls, clouds begin to appear, and a still further decrease of temperature condenses this watery vapour to water, and it falls as rain. The density of water is a very different thing from the density of vapour of water, the former, as stated before, is 815 times the weight of air, but watery vapour is only about a half the weight of dry air. Strictly, the proportion is as ·6235 : 1 for watery vapour and air at the same temperature and under the same pressure.

The temperature of the atmosphere is greatest at the surface of the earth, and decreases 1° Fahr. for every 340 feet in height. The temperature of the air on the surface of the earth also varies with the height above sea level, and with local circumstances.

In Atkinson's *Practical Treatise on the Gases met with in Mines* will be found the following rule to ascertain the weight of a cubic foot of air at any temperature and under any pressure :— $\frac{1{\cdot}3253 \times I}{459 + t}$ where I = the height in inches indicated by the barometer, and t = the temperature by Fahrenheit's thermometer. The reason of the figures 1·3253 being used is because 459 cubic feet when the barometer reads 30 inches, weigh 39·76 lbs., but at 1 inch it is only $\frac{1}{30}$th of this, or $\frac{39{\cdot}76}{30} = 1{\cdot}3253$.

Wind is air in motion, and varies in direction and velocity. It has the same pressure as the still air, but may exert considerably more force in one direction, as a result of its velocity.

As the specific gravity, the symbols of gases, and atomic weight are frequently referred to, it is necessary that the student should thoroughly understand what these terms mean. The specific gravities of bodies are the relative weights of equal volumes of them. In order to express the difference between the weights of equal volumes, we fix upon one body and call its density 1 or 1,000. Bodies which have a greater specific gravity have that indicated by some higher number than 1 or 1,000; bodies which have a lower specific gravity by a number less than 1 or 1,000 according to their relative differences in weight. Water is taken as the standard of specific gravity for liquid and solid bodies. Gases are so much lighter than water that it would be inconvenient to make the latter the standard of specific gravity for elastic fluids. Air accordingly is substituted for it, and the specific gravity of air is called 1 or 1,000 as stated before. When the specific gravity of a gas is given, the fact is expressed that a vessel when full of air at a certain temperature and pressure, and containing 1,000 grains of air, will at the same temperature and pressure, with the vessel filled as before, contain only the number of grains of that gas stated as its specific gravity, and which may be more or less than 1,000. To ascertain the actual weight of a cubic foot of gas whose specific gravity is given, find what it would be at 32° and under pressure of 14·73 lbs. by multiplying that specific gravity by ·080728 lb., which is the weight of a cubic foot of air under the same conditions of temperature and pressure as stated by Atkinson in his *Practical Treatise on the Gases met with in Mines.*

Then as to symbols. The chemist divides the substances of which the earth is composed into elements, of which there are at least 63, but as some of these have been discovered in recent years, there may still be other discoveries made. For the sake of convenience and shortness in writing, symbols are used for these elements. They consist of the first (or the first and most characteristic) letter of the Latin name of the body, thus H O signifies water, or oxide of hydrogen, and when the two symbols are placed side by side they signify a compound of one atom of each ingredient, viz., of hydrogen and oxygen. In writing compounds the symbols of the elements are placed side by side, and as more than one atom of the element or elements may combine to form a compound, the number of atoms, when more than one, is written beneath. Thus $N\ O_5$ signifies a compound where one atom or equivalent of nitrogen unites with 5 atoms or equivalents of oxygen to form nitric acid, the 5 multiplying only the O or oxygen. $Fe_2\ O_3$, red oxide of iron, signifies a compound of 2 atoms or equivalents of iron (*ferrum*) to 3 of oxygen, each symbol being affected only by the number following it. When a number, on the other hand, is placed before or at the left hand of associated symbols, it signifies all which follow it as far as the first comma, + (plus) sign, or full stop. To prevent confusion, the numbers placed to the left of symbols are generally made as large as the alphabetical letters they precede. Thus 2 H O is two atoms of water; $3\ N\ O_5$ is three equivalents of nitric acid; $Fe_2\ O_3$, $3\ S\ O_3$ is persulphate of iron, a compound of one atom of red oxide of iron, and three of sulphuric acid. $2\ Na\ O + H\ O + P\ O_5$, is two equivalents of soda, one of water, and one of phosphoric acid.

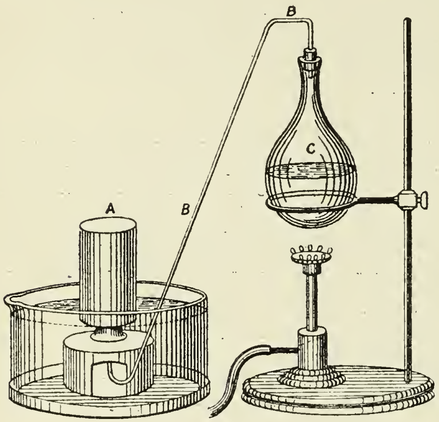


Fig. 316.—Illustrating Method of obtaining Oxygen Gas.

Atomic weight, or, as it may be called, equivalent chemical weight, is the term used to express the relation that subsists between the different proportions by weight in which substances unite chemically with each other.

Oxygen when uncombined is a gas, and is the most widely diffused body in nature; it forms $\frac{1}{5}$th part of atmospheric air by volume, and $\frac{8}{9}$ths of water by weight. Its symbol is O, and specific gravity 1,105·7, so that it is about $\frac{1}{10}$th heavier than an equal volume of air. It is a tasteless, colourless, inodorous gas. In the atmosphere it is fitted to sustain life by being diluted with nitrogen.

Oxygen gas may be produced as follows* :—

Take an ordinary dish-tub, or large sized pan, to serve as a pneumatic trough. Next fix a shelf in it a few inches above the bottom. Pour sufficient water into the tub to just cover the shelf. Take some glass pickle-bottles filled with water and invert over the shelf, taking care to keep the hand over the mouth of each bottle until its neck is under water, so that the water in the bottle may be retained. The Florence flask, C, Fig. 316, contains a composition for making the gas

* For this and the other illustrated experiments for producing gases, see Cassell's *Science for All*, vol. I. pp. 279—286.

required, and consists of equal parts of chlorate of potash and oxide of manganese. B is a glass tube, bent by means of a spirit flame, so that its lower end may dip under the water contained in the pneumatic trough towards the orifice of the inverted bottle, A. A gas-burner or spirit lamp is placed beneath the flask, which is to be used as a retort, upon lighting which the gas rises in bubbles and displaces the water contained in the bottle. The first few bubbles which pass consist of the air contained in the flask, and must be allowed to escape, after which the gas, which is pure oxygen, may be allowed to fill all bottles one after the other.

The phenomenon called combustion is caused by the union of certain bodies with the oxygen contained in the air: combustibles placed in undiluted oxygen, such as that contained in the pickle-jars, will burn with unusual energy. A match bearing the least trace of a spark will, when immersed in the gas, burst into flame. A piece of iron wire which has been tipped with sulphur and inflamed, will, when placed in the gas, burn away with remarkable brilliancy. If an india-rubber bag or a bladder be filled with oxygen, and a common blow-pipe be fitted to its neck, the gas may be forced out in a stream upon a rough

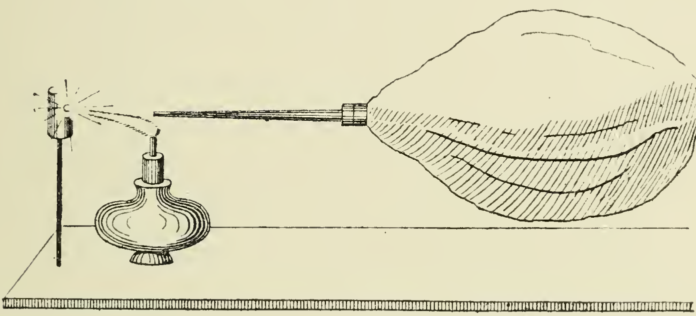


Fig. 317.—Experiment for Producing the Lime Light.

nail or any piece of iron held in the flame of the spirit lamp, and as a result the metal will be rapidly consumed. If, instead of the iron, the gas be projected upon a cylinder of chalk, the dazzling lime-light is produced. Fig. 317 shows the arrangement for producing this light experimentally; but when required for active service, a special jet is used, by which a mixed stream of hydrogen and oxygen is urged upon the lime. The heat obtained by this means is so great that platinum, the most refractory of the metals, is quickly reduced to a liquid condition.

A mixture of two volumes of hydrogen with one volume of oxygen may be made to combine to form water. But as they do so with explosive force, the experiment must be carefully conducted.

The oxy-hydrogen blow-pipe is capable, by its intense heat, of liquefying and volatilising all the metals, and even such substances as rock-crystal and clay. The mixture of the two gases forms such an explosive compound, that a special form of burner is used, so constructed that they are not allowed to mix until they reach the place of ignition. Fig. 318 shows the principle of the jet usually employed, B being the supply pipe for the hydrogen, and A for the oxygen. The lower part of the figure shows the kind of furnace used for the reduction of platinum. It consists of two fire-bricks hollowed out for the reception of the metal, the orifice above being for the introduction of the blow-pipe flame.

Nitrogen forms $\frac{4}{5}$ths of atmospheric air by volume. Its symbol is N, and its specific gravity 971·3, so that it is a little lighter than air. It is a colourless,

inodorous and tasteless gas. It will not support combustion, but is fatal if breathed in a pure state.

Nitrogen gas can be best obtained by robbing a given amount of air of its oxygen, when nitrogen will remain. Phosphorus has such an affinity for oxygen that it will combine with it very readily, leaving the nitrogen of the atmosphere in which it is burned untouched. A small piece of phosphorus, Fig. 319, carefully dried upon blotting paper, is placed in a porcelain cup, and supported on a stand in a dish of water. After igniting the phosphorus with a hot wire, the whole is quickly covered with an inverted glass jar. A graduated paper scale may be pasted on the jar, dividing it into five equal parts. When the phosphorus is

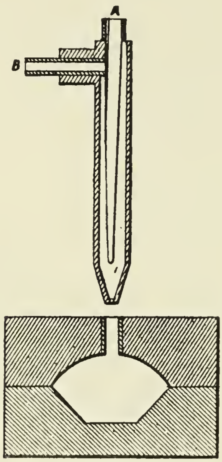


Fig. 318.—Oxy-Hydrogen Burner and Furnace for the Reduction of Platinum, &c.

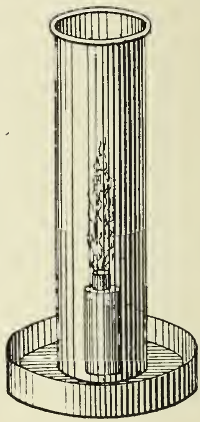


Fig. 319.—Experiment for obtaining Nitrogen Gas.

burning the water will rise in the jar, as nearly as can be judged, one-fifth, showing that that amount of air—really its oxygen—has disappeared, leaving the nitrogen for examination. If a lighted taper be now placed within the jar, it is immediately extinguished. Although the gas does not support animal life, it is not poisonous in the sense that some gases are, for we know that we are always breathing it.

Blowers of nitrogen gas issued from the rock in the Strinesdale tunnel during its driving. The gas escaped from fissures in the roof, sides, and floor of the tunnel, and candles at a distance of eighteen inches were extinguished. It seriously affected the health of the workmen engaged in the tunnel, producing feelings of sickness and dizziness. Occasionally, instead of the gas escaping through the fissures, the current was reversed and the flame of a candle when placed near an opening was drawn into it. The fissures were supposed to communicate with disused colliery workings in the neighbourhood. The blowers lasted some months and escaped with gradually decreasing force.

Nitrogen is the active principle in all explosives, from gunpower to nitroglycerine.

GASES MET WITH IN COAL MINES.

Carbonic Acid, or Carbonic Anhydride.—Its symbol is CO_2, that is, it is composed of one atom of carbon and two atoms of oxygen. Its specific gravity is 1,524, therefore it is about half as heavy again as air, and for that reason, before being mixed with the air, it rests on the floors of mines. It is called *choke-damp*, *black-damp* and *stythe* by the miners, and is colourless and invisible, having a sharp odour and taste. It is composed of 72·73 per cent. by weight of oxygen, and 27·27 per cent. by weight of carbon. A cubic foot of air at 32°, and under pressure of 14·73 lbs. per square inch, weighing ·080728 lb., and the specific gravity of carbonic acid being 1,524, to find the weight of a cubic foot of the latter under the same conditions of temperature and pressure, $\cdot 080728 \times \frac{1,524}{1,000} = \cdot 12303$ lb. Being a direct product of combustion, when any substance containing carbon is burned in the air, it cannot support combustion. On the contrary, it is uninflammable, extinguishes combustion, and a common test as to its presence is given by a candle going out if placed, when lighted, in air containing 10 per cent. of carbonic acid gas. The flame is not extinguished because oxygen is excluded, as is the case with nitrogen, but because carbonic acid exercises a prejudicial effect on combustion. Air containing 3 or 4 cent. of carbonic acid gas is unfit for respiration, and air containing only ·35 per cent. of it is very unwholesome when inhaled. Air containing 6 per cent. of carbonic acid gas is dangerous to breathe, and in the proportion of 8 or 10 per cent. is fatal to life. During animal respiration, carbonic acid is given off from the lungs; it is yielded naturally in some mines, and is produced by the burning of candles and lamps and from exploding gunpowder. Water dissolves more than its own volume of this gas, and in consequence acquires a sparkling appearance, and a refreshing, slightly stimulating, taste. In the manufacture of soda-water, and other effervescing liquors, carbonic acid is dissolved in the water in order to give it this taste.

The amount of carbonic acid gas yielded in a mine from animal respiration or as a product of combustion is easily dealt with by the ordinary means of ventilation. In mines, where it is emitted from the strata, or liberated from water which may have absorbed it in penetrating into the mine, to afterwards part with it on a change of temperature or pressure, the removal of the gas is more difficult on account of the large quantity to be carried away.

Some coal-seams are subject to "blowers" of carbonic acid gas, very much in the same way as others are subject to "blowers" of fire-damp. It is not probable that the same seam will supply blowers of both. It is supposed that the mode of occurrence of the two gases in the coal is the same, and both will be frequently found in the vicinity of faults. Where blowers of carbonic acid gas have been tapped, an enormous quantity of gas under pressure has been given off, laying the workings off for many days and extending very far into them. The issues of this gas underground, whether under a certain pressure as in the case of a "blower," or pouring out of old workings without pressure, are silent. No indication of its presence is conveyed therefore by the sense of sound to those approaching any workings in which it is found. Instances are recorded where the issue has been felt against the back of the hands very similar to cold air being blown through the stem of a tobacco pipe, but always without the singing noise which accompanies discharges of fire-damp.

Carbonic acid gas is most commonly found in dip workings, on the floors of roadways, or at the foot of steeps in rising return air-ways, owing to its specific gravity. Many lives have been lost where men have descended wells and shafts without first taking the precaution of testing them for this gas. Sumps of pits, wells, or dismantled pits, should be tested to see if this gas is present before a

person descends. If present in dangerous quantities the flame of a lamp lowered into it will be extinguished. It may be removed by quicklime in the process of slaking, which absorbs the gas; or by letting water fall, which carries air with it, so as to mix with the gas; or it may be drawn up, by lowering buckets into it just as though it were water.

The method of producing carbonic acid gas is very simple. Through the tightly-fitting cork of a wide-mouthed bottle insert a glass tube bent twice at right angles, one limb of the tube being much longer than the other, see Fig. 320. Into the bottle put some hydrochloric (muriatic) acid, diluted with a similar quantity of water, and into the mixture drop a few pieces of chalk or limestone. A brisk effervescence will ensue, caused by the escape of the carbonic acid in bubbles from the chalk. The long end of the tube is inserted into another bottle, which soon becomes filled with the gas. To ascertain if the bottle is filled, put

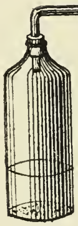


Fig. 320.—Experiment for obtaining Carbonic Acid Gas.

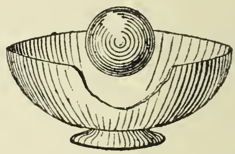


Fig. 321.—Ball resting on Carbonic Acid Gas.

into it a lighted match or taper, which will be extinguished as soon as it reaches the surface of the gas. As showing the extreme heaviness of carbonic acid gas, half-fill an open basin (Fig. 321) with it and place a child's india-rubber ball or a soap bubble on the surface. To the uninitiated the ball seems to be suspended in mid-air.

Carbonic Oxide.—Its symbol is CO; one atom of carbon and one of oxygen. Its specific gravity is 975, being rather lighter than air. Out of every 100 parts by weight there are 56·7 of oxygen and 43·3 of carbon. By the miners it is called white-damp. It is colourless, tasteless, and poisonous; it has a slight and peculiar odour. It does not in the ordinary sense support combustion, yet, singular as it may seem, candles and lamps will burn in a mixture of it with air, which at once destroys life. It is more poisonous than carbonic acid gas; air containing 1 per cent. is at once fatal to warm-blooded animals breathing it. The effects of a trace of it in the air, if breathed, are a sensation of giddiness, sickness, debility, and fainting fits. Its most striking property is that it is itself combustible, burning with a beautiful blue flame, combining with the oxygen of the air, and forming carbonic anhydride (CO_2).

Carbonic oxide is a narcotic poison, and, like carbonic anhydride, enters the blood through the lungs. Its presence in the blood can be detected after death. If a considerable quantity of carbonic anhydride be contained in the air, to which only $\frac{1}{2}$ per cent. of carbonic oxide be added, the mixture if breathed is fatal to human life.

The report of the French Fire-damp Commission gives the temperature of ignition of this gas at 1,202° Fahr. It is found in mines as a result of exploding gunpowder, because it is a product of the explosion, and from the combustion of coal or wood under certain conditions, particularly where there is a restriction of air. In mines where the ventilation is good, and constantly maintained so, this

gas is not met with. In mines insufficiently ventilated, and where gunpowder is freely used for blasting, the circumstances are favourable to the presence of carbonic oxide gas. The fumes then given off by blasting have a most disagreeable odour, greatly irritating the organs of respiration, and sometimes proving fatal to those who inhale them.

The Commissioners appointed to inquire into Accidents in Mines, state in their report that the presence of this dangerous gas in after-damp has never been clearly proved, but its existence is possible in that resulting from an explosion consequent on an outburst of gas. When a coal-seam, or the gob, is on fire, the gas is produced in large quantities owing to the imperfect combustion, through efforts made to exclude the air from the fire.

Carbonic oxide contains an atom less of oxygen than carbonic anhydride. If the latter be passed through a red-hot iron tube, it is converted into carbonic oxide, as it is deprived of half its oxygen by the iron during its passage.

To produce the gas for experimental purposes place the deadly poison oxalic acid in the shape of small white crystals, together with strong oil of vitriol, in a Florence flask. From the tightly fitting cork of the flask a tube leads upwards and is bent over like the letter U inverted, its lower end being passed through a tightly fitting cork in a double-necked bottle containing lime-water or caustic potass, the tube reaching to within a short distance of the bottom of the bottle. From the other neck of the bottle a bent tube is placed, communicating with the interior of the bottle at its upper extremity and a trough containing water. The gas-jar for collection is placed in an inverted position in the trough, and the tube from the bottle leads to it. On lighting the spirit lamp under the flask the temperature of the oil of vitriol is raised until it attains a point sufficient for the purpose, when carbonic oxide and carbonic anhydride gases are evolved with great rapidity and pass from the flask into the bottle. Here the solution of potash or lime-water absorbs the carbonic anhydride, whilst leaving the carbonic oxide free to pass to the upper extremity of the bottle and so to the trough where the gas-jar is filled with it.

Sulphuretted Hydrogen or Hydrogen Sulphide.—Its symbol is H_2S, two atoms of hydrogen and one atom of sulphur. Its specific gravity is 1,171, and it is therefore rather heavier than air. It is this gas which imparts to rotten eggs their offensive smell, and it may be recognised by its odour. It is colourless and very poisonous, and even when largely diluted with air acts as a powerful narcotic. It does not support combustion or respiration, but is itself combustible and burns with a blue flame. Water dissolves from two-and-a-half to three times its volume of the gas and acquires its offensive odour and taste. Consequently, it may be carried into mines in a state of solution by water and afterwards liberated. The water which drains through decomposing pyrites, has a muddy, iron colour, and exercises an injurious effect on iron rails, pumps, &c., and upon articles made of leather, such as boots, &c. H_2S is found in mines as a result of the decomposition of pyrites, or of some animal substance containing sulphur, and also as a result of exploding gunpowder.

The chemical name for pyrites, or iron pyrites, is sulphuret of iron. Pyrites is found in irregularly shaped lumps or nodules, and often in continuous layers, or "partings" in coal seams, when, owing to its yellow, metallic appearance, it is called "brass" or "brasses."

The exact proportion of sulphuretted hydrogen fatal to life is not known, but it produces fainting fits when present in very small proportions; different authorities give from $\frac{1}{2}$ to 4 per cent. Air containing $\frac{1}{1500}$ of its bulk immediately killed a bird, and $\frac{1}{1000}$ a middle-sized dog. Lights continue to burn in it, however, and its presence can only be detected by its odour. It is rarely met with in mines, except as part of a mixture containing several gases.

The sulphuret may be prepared by heating sulphur and iron filings together in a crucible, or by placing a stick of roll sulphur against a bar of malleable iron at a white heat. The result in both cases is to form a compound of one equivalent of sulphur and one of iron (FeS), which on being dissolved in diluted sulphuric acid yields sulphuretted hydrogen.

Proto-Carburetted Hydrogen, or light carburetted hydrogen, is the "fire-damp" or inflammable gas met with in mines. Its symbol is CH_4, one atom of carbon and four atoms of hydrogen. Its specific gravity is 562; it is therefore rather more than half as heavy as air. Owing to its lightness, its tendency is to rest against the roofs of mines, and in cavities, unless it is displaced by air currents acting upon it. By a property all gases have, called *diffusion*, it gets mixed with the air. It is a colourless, inodorous gas, scarcely soluble in water, and does not support combustion or respiration. It is not a poisonous gas, but if breathed in a pure state it causes death, because it does not support respiration. If mixed with twice its own volume of air it may be breathed for some time without much injury resulting. It issues as a product of decomposition from the seams of coal, and when it mingles with the air in certain proportions it forms an explosive mixture. Any flame applied to the mixture causes explosion, and many sad and destructive accidents of this description are brought under our notice. Sometimes olefiant, or heavy carburetted hydrogen (C_2H_4), becomes mingled with the fire-damp in the atmosphere of a coal-mine, and this compound may be fired with a red-hot iron or wire. Under other circumstances, fire-damp can only be exploded by coming into contact with flame, or with a wire or other substance at a higher temperature than a red heat, such as that in an incandescent electric lamp, and it must then be mixed with certain proportions of air, as it cannot be exploded in a pure state. The force of such explosion will be dependent upon the proportion of fire-damp to the air and the presence or absence of carbonic acid in the mixture. Carbonic acid, we have already seen, does not support combustion, but it cannot influence an explosion of fire-damp much, because a large quantity could not be present in an atmosphere fit to breathe. The effect of putting a lighted candle or lamp into pure proto-carburetted hydrogen gas would be to extinguish it.

When CH_4 forms 1 part in 30 of an air-and-gas mixture, its presence may be detected by the "cap" formed on the flame of a safety lamp. When it forms 1 part out of 13 of the mixture, it may be ignited by a flame, and the whole of the mixture will be converted into a mass of flame, but its force will be feeble. The explosive force, however, increases as the ratio of the gas to air increases from 1 to 13 to 1 to 8 or 9, at which point it attains its greatest force; but explosions will occur with a diminishing force as the ratio of the gas to air passes from 1 to 8 or 9 to 1 to 5, after which the mixture, instead of exploding, extinguishes the flames of lamps.

The French Fire-damp Commission gives the temperature of ignition of this gas as 1,436° Fahr., but the report of the Prussian Commission gives a much higher temperature of ignition, as silver and copper wires were fused without igniting it.

Some seams of coal give off much more fire-damp than others, and many give off none at all, consequently, at some collieries it is never found, at others, only in small quantities, whilst in many, such large quantities are yielded as to cause considerable anxiety to all engaged in the mine.

The origin of the existence of gas in coal is a matter of uncertainty. The coal being formed from vegetable matter, it is quite possible that during the process of decomposition, new strata accumulated to such an extent as to cause considerable pressure. Where these newly deposited strata were of a porous nature, the gases given off during decomposition would escape through the strata to the

surface, but where the cover over the buried vegetable matter was impermeable, the gases were retained at increased pressure as decomposition proceeded and the coal-seam fully matured. Most probably the gas is contained in coal-seams as water is in a porous rock, and remains there in a more or less compressed condition so long as the enclosing walls are gas-tight and able to withstand the pressures from within. Probably the coal is still in a state of chemical change or decomposition, which may be proceeding very slowly, and thus gases are continually evolved and accumulated within the pores of some coals. If the roof over the coal be of an impermeable rock, and the thill be composed of porous sandstone, the latter will be found to contain gas, or if the cover immediately over the coal be porous, it becomes a gaseous zone. If the shafts are shallow, and there are no impermeable rocks between the surface and the coal-seam to retain the gas, it will be drained off to the surface. A seam of coal may in some parts of its course have but little cover over it and be quite free of gas at those points, whilst at others, owing to thicker stratification above, or the setting in of an impermeable rock which retains the gas, it may contain large volumes under great pressure. Again, two coal-seams may be separated by impermeable strata, but on working the upper seam the intervening strata, robbed of so much support, become unable to resist the pressure of gas in the lower seam, and, consequently, the floor of the seam being worked is raised and fractured. The fissures formed enable large quantities of gas to pass from the seam below into the workings. The amount of gas contained in any seam does not depend on its depth from the surface, although it seems to be present more abundantly in mines of moderate depth. Seams of lignite coal are usually free from it, and it is only in true coal-seams that large quantities are found.

The gas, for the most part, disengages itself from the pores of freshly-wrought coal, or from the joints of recently exposed coal surfaces; in most seams the issue occurs in the first few hours, and ceases after a few days. The largest volume is usually found at the working faces, where it issues in innumerable jets, as the workmen constantly extract coal and so lay bare fresh coal surfaces. In damp or wet seams, the discharge of gas from the coal is accompanied by a hissing sound, and in these the discharge, instead of ceasing in a few days, continues for months or even years.

In mines where the largest volume of fire-damp is not found at the working faces, but at a point back behind them, it will generally be found that the gas has drained to the point of discovery, through the strata, from a lower seam of coal in course of working, whose line of advancing face lies outside that in which the gas is, or it may come from a lower unworked seam, or from an exceptional outburst.

Exceptional outbursts are either *blowers* or *outbursts*. Blowers are continuous discharges of firedamp for long periods of time, without apparent decrease, through well defined cracks or fissures in the roof or the floor of roadways. Sometimes the discharge of gas is accompanied by large quantities of water. When the gas can be detected at the point of issue by a safety-lamp it is sufficient to constitute a blower. The fracture through which the gas is discharged—whether a simple fissure or a fault—pre-existed, and on the driving reaching it the gas is tapped. The open fissures in the coal seam communicate with some reservoir filled with large quantities of gas in a high state of tension. Where the fractures do not allow sufficient gas to escape, or where the pressure of the gas is so great as to cause it to find vent before the fissures are reached by the drivings, or where reservoirs of gas exist without fractures, falls of the roof or upheavals of the floor occur, followed by the release of enormous quantities of gas into the roadways. As showing the power of these blowers, it may be stated that at Outwood, in West Lancashire, at a depth of 328 yards, a blower of great magnitude was encountered in a stone drift, causing operations to be suspended. The gas was dammed off,

and taken to the surface by means of pipes 2 inches in diameter, where it burned with a flame 3 feet 6 inches high for a year.

At Merthyr Vale, in South Wales, so large a quantity of gas was met with on crossing a fault into a new area of coal, about a mile from the shaft, that it was deemed prudent to convey the gas separately to the surface, where it was utilised for several months in raising steam by being burned at the boilers. The pipes, which were 6 inches in diameter, were laid from the inside of a strong dam near the fault, through the return airway to the upcast, and thence to the surface.

Outbursts of inflammable gas are distinguished from blowers by the suddenness of their appearance, and their comparatively quick exhaustion. An outburst may occur at the working face, or from the roof or the floor. Those from the floor present the most marked features, and it is in the Barnsley and Silkstone seams of Yorkshire that they occur with the greatest intensity and frequency.

These outbursts have been commented upon in the Chapter devoted to "Methods of Working," where the working of the Barnsley seam is described. As the workings approach the reservoirs of gas under the seam the floor is upheaved, and fractured in a line approximately parallel to the advancing face. This is the result of the pressure from the imprisoned gas, which finds its way first into the working faces through the fracture, and from there into other parts of the mine. In 1876 an outburst occurred at the New Oaks pit in the rise long-wall workings of the Barnsley seam, ventilated by a current of 10,000 cubic feet per minute. The returns became so loaded, that Mueseler lamps at the bottom of the upcast were extinguished in a current of 140,000 cubic feet per minute.

Outbursts from the roof result from large quantities of gas following the falling of the roof, or from the escape of gas from fissures in the roof without a fall.

At an outburst at Pelton, in the county of Durham, 47,000 cubic feet of gas issued from the coal at a pressure of 912 pounds to the square inch.

Instances are recorded where the pressure of the gas has been sufficient to force out the coal in large masses of many tons' weight at the working faces, after which it escaped suddenly through the opening thus formed in such volumes as to constitute an outburst. The enormous volume given off has been powerful enough to foul a considerable area of workings and so prevent access to them for many days, notwithstanding the fact that a large current of air has been sent continuously into the district. In an occurrence of this sort, after a time the pressure of the gas decreases and the fresh air-current sweeps the roadways to a point nearer and nearer the face, and as the pressure subsides, to the face itself.

Occasionally rows of props which were originally fixed securely for the protection of a roadway, have been observed to sink at the foot until they become loose and eventually fall out. This is accounted for by the tapping of gas into the working seam from a stratum below, which previously served to support the floor in which the props were set. The gas pressure being removed, the coal and underlying strata have sunk, and the props collapsed.

The shots fired in sinking pits have been often known to liberate firedamp from fiery seams on the sinking approaching the coal. In cases where the gas has caught fire, the flame has reached up the shaft to a considerable height, requiring much trouble to extinguish it.

In 1879 experiments were made by Mr. Lindsay Wood, for the Royal Commission on Accidents in Mines, in the various seams at Elemore, Hetton, Eppleton, Boldon, and Harton Collieries, with a view to ascertain the pressure of fire-damp in the solid coal, and also the quantity yielded in a given time from a certain face area where the coal was newly wrought.

Many experiments were made by boring holes of different lengths, either horizontally or slanting slightly upwards, but always at freshly worked faces, the holes being rapidly bored, a pipe smaller than the hole drilled being subsequently

inserted, of sufficient length to reach nearly to the end of the bore-hole. The longest bore-hole was 47 feet, and the shortest $3\frac{1}{2}$ feet. The space between the pipe and the bore-hole was equally stemmed from a point near the inside end of the pipe, which there carried a protecting flange the full size of the bore-hole back to the working face. The flange prevented the stemming from being pushed too far, and ensured its equal distribution round the pipe. At its outer end the pipe was provided with a tap and pressure-gauge, whilst its inner end was open to the gas space reaching from its extremity to the end of the bore-hole. The highest recorded pressure was obtained at the Boldon Colliery, where about the third day after attachment the pressure-gauge indicated 461 lbs. per square inch. The greatest observed amount of gas given off from the holes was 5·927 cubic feet per hour per square foot of surface, and this occurred in an experiment at the Eppleton Colliery. Pressures varying from 200 lbs. to 461 lbs. per square inch were repeatedly observed; the depths of the places also varying from 750 feet to 1,268 feet below the surface.

Besides the exceptional outbursts just described, discharges of fire-damp from old into existing workings may occur. Old workings or goaves frequently receive discharges of gas, and become, as it were, magazines in which the dangerous element is stored. The gas in the old workings may come from the normal discharge of the seam being worked, or it may come from adjacent seams.

A large number of shots fired in the coal simultaneously at the working face may result in liberating an undesirable quantity, and therefore only a small number are fired at once in fiery mines, and that only by competent persons.

Under the ordinary conditions of a well-regulated mine, no inconvenience, perhaps, arises from the presence of this gas; but it becomes an acknowledged source of danger when, as frequently happens, it finds its way, owing to the sudden decrease of atmospheric pressure, or falls of the roof on a large scale, into the working roadways closely adjoining the edges of the goaf or old workings.

Attempts have been made to capture fire-damp at the moment of its disengagement from the freshly-wrought coal. The method consists in laying a series of pipes into the face of all the working places, connected with a main pipe leading to a powerful exhausting machine upon the surface. Similar attempts have been made to withdraw the fire-damp from goaves, but the method is not capable of very practical application.

Earthquakes, accompanied by earth motions, sometimes produce abundant escapes of gas at the surface, and it is possible that the position of reservoirs of gas may be also affected by fissures accompanying such motions. An earthquake may change the position of a gas reservoir in the earth's crust, or form others in fissures left by it which did not previously exist. Investigation is now being made as to whether abnormal issues of fire-damp are caused by seismic movements.

In approaching faults in fiery seams and after crossing them, the gas is frequently discharged freely. It sometimes rushes from the neighbourhood of faults, and rises through a column of water many yards high.

Mixtures of fire-damp and air may become altogether inexplosive if sufficient carbonic acid gas or free nitrogen be allowed to mix with them. Even small quantities of these gases when present in the mixture, lessen the explosive force on ignition. *After-damp*, resulting from an explosion of fire-damp and air, consists of 71·2 per cent. of free nitrogen, 9·6 per cent. of carbonic acid gas, and 19·2 per cent. of steam, or in round numbers out of 10 parts, after-damp contains 7 of nitrogen, 1 of carbonic acid gas, and 2 of steam. Directly after the explosion the steam condenses, and there is then left out of $8\frac{1}{2}$ parts, about $7\frac{1}{2}$ of nitrogen and 1 of carbonic acid gas. Breathing after-damp soon causes death, and many who escape the force of a fire-damp explosion in mines fall victims to the deadly after-damp.

If an explosion occurs in which the fire-damp forms more than 1 in 8 or 9 of air, its force is less than that of the most destructive proportions of fire-damp and air, as a certain amount of the gas remains as such, which, if consumed, would have increased the temperature and force of the explosion. Its presence after the explosion renders the after-damp more deadly. Again, if an explosion occurs in which the fire-damp forms less than 1 in 8 or 9 of air, its force must be less than that of the most destructive proportions of fire-damp and air, but in this case the after-damp will be rather less deadly than that resulting from the most violently explosive mixture, as a part of the oxygen in the air remains unchanged. Whatever the proportion of fire-damp to air, the after-damp left from its explosion is unfit to breathe.

When ignited, the flame temperature of fire-damp and air is extremely high, and where there is a large volume of the explosive mixture present, the temperature of the portion being consumed increases the volume of the rest. From the centre or seat of explosion a great pressure is caused by the flames and heated gases, which proceed in every direction, driving the air away with great force; this pressure is exhausted at a distance near to, or far from the seat of the explosion according to its violence. As it progresses the condensation of steam in the after-damp reduces its volume and pressure until it descends sufficiently to cause a backward movement, and a partial retreat of the ignited mass towards the seat of the explosion ensues.

The ravages committed by these destructive blasts are familiar enough to explorers after explosions. As the conflagrations march on along the roadways, they for the most part take a course opposite to that of the intake air, with occasional "kick-backs," or slight splits at the junctions of roads, and as the flames are fed by the fresh air, the blast, if supplied by sufficient fire-damp, or fire-damp and coal-dust, it may be reaches the bottom of the downcast shaft, and exhausts itself in the shaft, disarranging or perhaps blowing out nearly all the shaft fittings with so much violence and noise as to cause the utmost terror to those employed on the pit top. In its destructive progress everything presenting an impediment, unless strong enough to resist the blast, is hurled to one side or overthrown; doors, air-crossings, trams, horses, men, the timbers for securing the roadways, &c., usually offer no obstacle to the fury of the explosion. The road timbers being knocked down the roof falls in, and the ventilation is arrested. In other parts of the roadways the timbers are considerably charred and deflected from an upright position, their altered state and appearance pointing almost as certainly as a finger-post in the direction of the blast. Too often the evidence of such mute objects is all that is to be obtained, for those who escape the violence of the explosion are poisoned by the after-damp, and not one is spared to throw light on the calamity.

Wet roadways naturally check the progress of an explosion of fire-damp, and it is in dry and dusty mines that the worst occur. The violence of the blast in these is arrested through any portions of the roads which are wet, however the dampness is caused.

Coal-gas is obtained from the distillation of coal, and is nearly allied to fire-damp, although the gases are quite distinct. The preparation of coal gas may be effected on a small scale by means of a common "long clay" tobacco-pipe.

Fill the bowl with coarsely powdered coal and seal it up with a cover of moist clay. When the clay has sufficiently dried, the bowl must be exposed to a red heat in an ordinary fire-grate. The gas with a quantity of smoke will soon be generated and can be lighted at the mouthpiece of the pipe. What is left in the now red-hot bowl of the pipe, is a lump of nearly pure carbon in the form of coke.

If a mixture of ordinary coal-gas and air be fired in a closed vessel at atmospheric pressure, it produces a maximum pressure of 100 lbs. per square inch and

a flame temperature of 3,600° F., or higher than that of cast-iron running from a blast furnace. Possibly in pit explosions a somewhat similar temperature is attained.

The Diffusion of Gases.—This property is the influence of a force powerful enough to resist the influence of gravitation, and causes a blending or mixing of gases through each other, notwithstanding their different specific gravities. When light and heavy gases are exchanging places, a larger volume of the light gas passes in one direction than of the heavy gas in the other. When these gases have become thus mixed they will remain so. It is this diffusive force which maintains the atmosphere uniform in constitution. The property of diffusion is only thoroughly carried out where the gases are still. It has little influence for good on the ventilation of mines, and is entirely inadequate as a means of rendering harmless the noxious gases there met with. On the contrary, it is a means of forming inflammable mixtures of gas and air in all quiet nooks and cavities into which fire-damp finds its way.

THE VENTILATION OF MINES.

From what has been said of the gases in mines it will be readily seen how necessary it is to provide a current of fresh air to take the place of that which has been rendered impure. A supply must be produced and distributed through the workings. Without provision being made, a certain amount of natural ventilation takes place in mines.

The reason of this is, that the same law which causes a rise or fall of the atmospheric currents over the face of the earth operates also below its surface. The temperature of the rocks for the first 50 feet or thereabouts is influenced to a slight extent by the changes of temperature on the surface, but below that depth it is the same all the year round. Beginning with 50° F., at a depth from the surface of 50 feet, this temperature increases 1° F. for about every additional 60 feet of depth. The temperature of the rocks in the workings of a shaft 700 feet deep would be then about 61° F., a higher temperature than that of the air on the surface in winter, but a lower temperature than that of the air on the surface in summer, so that the air in workings of moderate depth will be warmer in winter and cooler in summer than the air at the surface. The colder column of air will press upon and displace the warmer. Suppose (Figs. 322 and 323) two shafts at some distance from each other, having a different surface level and connected at the bottoms of the shafts by a gallery.

In the winter, when the air on the surface is colder than that of the gallery, the column of air in D E is cooler and heavier than the column of equal height A B; consequently the cold air displaces the warm, and so produces a current in the direction shown by the arrows in Fig. 322. This result, as regards direction of current, would not be effected by the size of the shafts or of the gallery connecting them. In the summer, when the air on the surface is warmer than that of the gallery, the column A B is cooler and heavier than the column of equal height, D E, and the direction of the air current would be reversed as seen at Fig. 323. But at certain seasons between these two extremes the two columns would balance each other and the current of air cease to circulate. The more nearly the two shafts approached the same surface level the more feeble would be the current in summer and winter and the more liability there would be for it to cease at other times. In by far the largest number of mines natural ventilation is totally inadequate, and even under the most favourable circumstances it cannot be relied upon. Therefore artificial means are necessary to promote ventilation in a certain definite direction, so as to ensure sufficient currents of air circulating from the downcast through the workings to the upcast shaft.

In the early history of mining the *furnace* was resorted to for ventilation, and is still used in many mines, the furnace being placed at the bottom of the upcast shaft. The fire heats the air and by expansion renders the column of air lighter, and in consequence of this the colder and heavier air passes down the downcast to displace it. The furnace may be placed in the return airway if the shaft is only used for ventilation and no explosive gas is given off in the mine. If the position chosen for it be in rock, a single archway may be built over the furnace with fire-brick, but if it has to be placed where coal or shale forms the sides or roof, it will be necessary to remove some of it on each side, so that side arches may be built to protect the sides and roof from fire, and provide a passage for the circulation of air.

If it is necessary to use the return airway for purposes other than ventilation, some other place must be selected for the furnace and a connection made with the return airway. The furnace is usually from 5 to 10 feet wide and the fire-bars 6

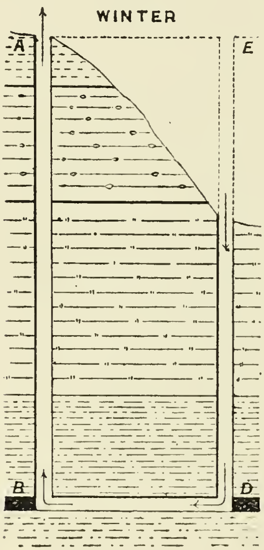


Fig. 322.

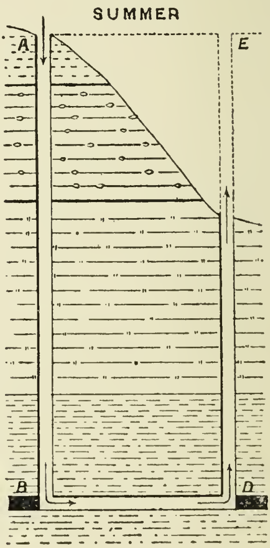


Fig. 323.

NATURAL VENTILATION.

feet long, the space above being from 3 to 5 feet to the arch and below about 4 feet. A good plan is to let the breadth equal the diameter of the upcast shaft and to let the sectional area of the furnace drift be not less than the sectional area of the upcast shaft. The length of a furnace should not exceed 8 or 9 feet, and its breadth should not exceed 10 or 12 feet, because of the difficulty to feed and attend to the fire, and it is much better to have two furnaces than one large one. Figs. 324, 325, and 326 show in plan and section a double furnace with side arches.

All the work in contact with the flames of the furnace must be of fire-brick. The arches over the furnaces may be built with a thickness of fire-brick next the furnaces and have a blank space of a few inches interposed between the fire-brick and the ordinary brickwork beyond. The fire-bricks should be cemented together by ground fire-clay so as to effectually stand the heat from the furnace.

A well-constructed furnace will yield about 6,000 cubic feet per minute for each foot in breadth of fire-bars.

With a double furnace each grate of which is 8 feet wide, there would be there-

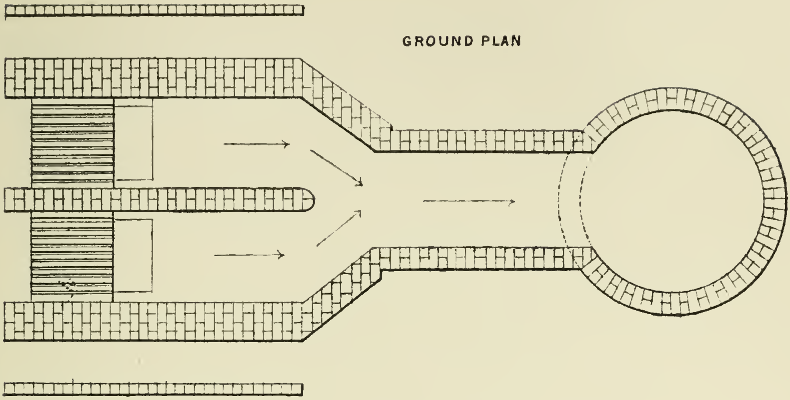


Fig. 324.

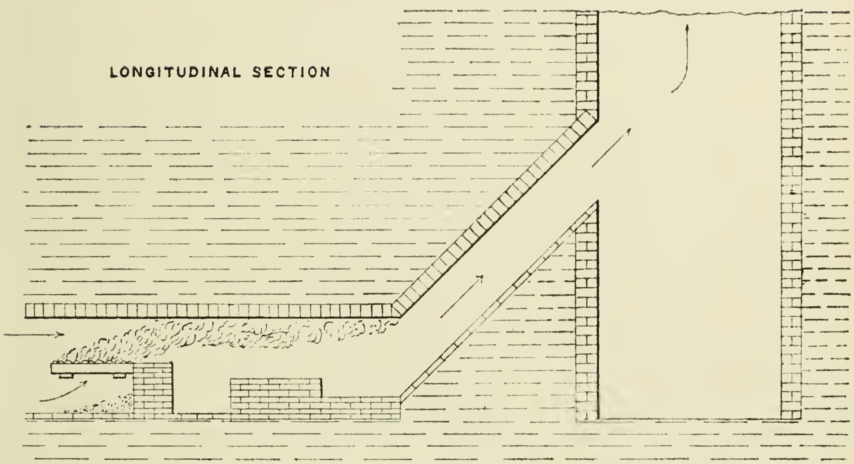


Fig. 325.

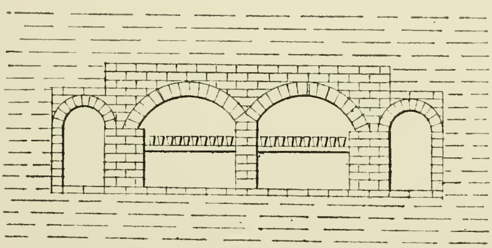


Fig. 326.

Double Ventilating Furnace.

fore about $16 \times 6{,}000 = 96{,}000$ cubic feet per minute passing over it. But the work yielded by a furnace is affected considerably by the depth from the surface at which it is placed. In all cases the quantity of air will be as the square root of the difference between the temperatures of the downcast and upcast shafts and also as the square root of the depth from the surface. All other things being equal the same furnace which is placed at a depth of 200 fathoms will produce double the quantity of air that it would yield at 50 fathoms. The horse-power of a furnace is calculated from the ascertained weight of the air in the upcast and downcast shafts, which will be more particularly referred to later on. Sometimes the fires of underground steam-boilers act as furnaces assisted by the heat of the exhaust steam from the engines. Where the return air is liable to be charged with explosive gas, it is often made to enter the upcast shaft by a dumb drift, the point at which such drift enters the shaft being not less than 8 fathoms above the end of the furnace drift, so as to ensure that the return air, if inflammable, shall not be ignited by the furnace. By the Mines Act, 1887, the return air, unless it be so diluted as not to be inflammable, must be carried off clear of the fire by means of a dumb drift or airway. The dumb drift should have an inclination of not less than 1 in 6, or the smoke is liable to flow back from the running of the cages or the opening of doors. If all the return airways to the shaft are charged with inflammable gas, none of them will be available to supply the furnace with air, and in that case it must be fed with fresh air from the downcast. The fire should be kept thin and coal thrown on frequently, so that the air may pass freely through the burning fuel.

The *waterfall* is an expedient for producing ventilation. It may be caused by allowing the pump cisterns to run over, or pipes may be laid for the purpose, the water being scattered and not falling in one stream. It is not a very efficient means of ventilation, nor a very economical one, as the water has to be pumped again, unless under the exceptional circumstances of the mine having an adit by which the water would run level free to the surface. However, it is a very ready way to obtain air under exceptional circumstances, such as after an explosion.

The *steam jet* is another of the artificial methods of ventilation. It consists of steam, which may be brought down the shaft, being allowed to issue in small jets from $\frac{1}{16}$th to $\frac{1}{8}$th inch in diameter directed upwards and placed in concentric circles round the bottom of the upcast shaft. It is not nearly so efficient as the furnace, and except in cases of emergency is not much resorted to.

Mechanical Ventilation, or that caused by the use of Machinery.—This machinery may be divided into two classes, viz., the varying capacity or displacement machines, and the centrifugal.

Dealing first with the *Displacement* machines, the oldest form of mechanical ventilator is the air-pump, worked by a steam-engine.

The *Struvé* is one of this kind, shown at Fig. 327. It consists of two close-topped airometers or pistons made of sheet-iron in the form of a gasometer, worked alternately, by means of a beam, up and down in a ring of water formed between the brickwork. Only one of the airometers is shown in Fig. 327, the other, similar to it, being placed at the other end of the beam. At the top and bottom of the walls of the chambers (of which there are two to each piston) are placed flap-valves, hung upon vertical gratings in the wood framing, and these valves are so arranged that in making the up-stroke as in making the down-stroke the air is both being drawn in and forced out. They are of course connected with a passage leading from the top of the upcast shaft, and the steam-engine placed on the surface usually works the two pistons by means of a beam, so that

there is an even flow of air up the shaft. The useful effect varies according to whether the flap-valves are new and in good order, or in an ordinary working condition. In the Report of the North of England Mining Institute Committee on Mechanical Ventilators, issued in 1880, they give the useful effect of the Struvé working at Cwm Avon Colliery, South Wales, at 57·8, and it stands highest on their list. It is not at present in use.

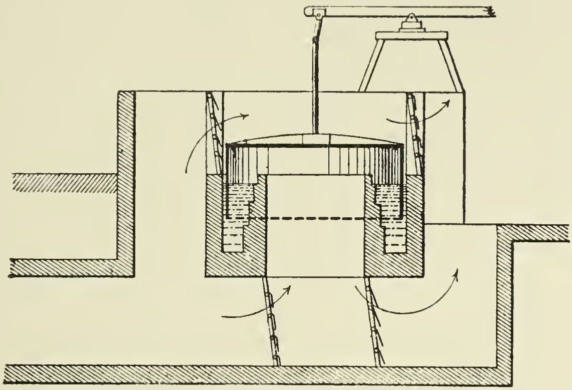


Fig. 327.—The Struvé Ventilator.

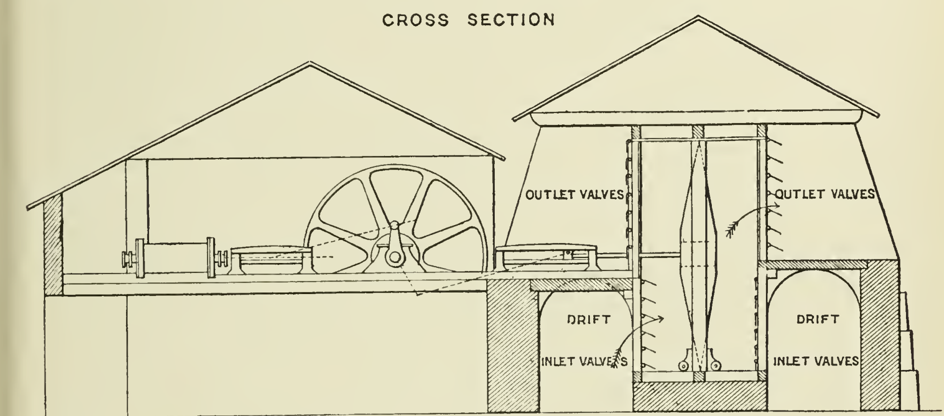


Fig. 328.—Nixon's Ventilator.

Nixon's ventilator, Fig. 328, is another of the air-pump kind. It is a horizontal double-acting air-pump, and the two rectangular pistons, which are of large size, are supported on wheels which run on rails. The lower half of each chamber is in connection with the pit when the inlet-valves are open; on the upper half of the chamber the outlet-valves are hung, and these communicate with the atmosphere. The valves are much the same in construction as those of the Struvé. With this kind of ventilator, if it were possible to close the downcast shaft and absolutely exclude the air from entering there, the ventilator, if perfect, would create a vacuum in the mine. The useful effect of the Nixon's ventilator, like that of the Struvé, must to a great extent depend upon the condition of its valves. In the Report already referred to, the useful effect of the Nixon ventilator working at the Navigation Colliery, South Wales, is given at 45·91.

The *Fabry* ventilator, Fig. 329, consists of two wheels of equal diameter on different shafts. Each axis is fitted with three broad blades from 6 to 10 feet wide, and each blade is formed with a cross arm, and, as the axes revolve in opposite directions, two of these are always in contact during revolution in the style of toothed wheels. The machine may be used for exhaustion or compression according to the way the wheels revolve. The bottom half of them fits into a brick casing, and the air from the shaft, if being exhausted, is taken up between the blades and afterwards discharged above the casing. The shafts which bear the two wheels are connected together by two ordinary wheels having the same circumference.

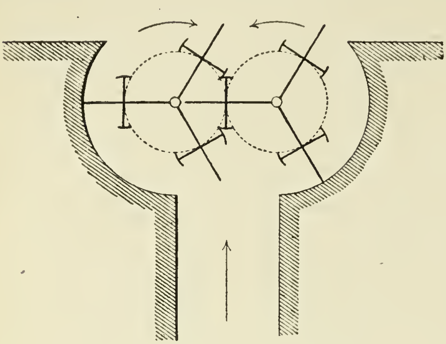


Fig. 329.—The Fabry Ventilator.

In the *Lemielle* ventilator, Figs. 330 and 331, a six-sided drum is placed eccentrically in the cylindrical brickwork, and revolves upon a vertical axis. Three vanes are attached by means of hinges placed at alternate corners of the six sides of the drum. The other ends of these vanes are joined to two connected rods which turn round a fixed shaft in the centre of the cylindrical brickwork, and this causes the vanes to set themselves to the constant change of position of the drum. By the revolution of the drum, spaces varying in capacity are formed, the largest occurring at the inlet from the mine and the smallest when passing the exhaust drift. The air is expelled by the vanes (which act in turns as pistons) as they approach the point of outlet. According to the North of England Mining Institute Committee's Report, the useful effect of the Lemielle ventilator at Page Bank Colliery, Durham, is given as 23·4, which is very low as compared with some of the other ventilators.

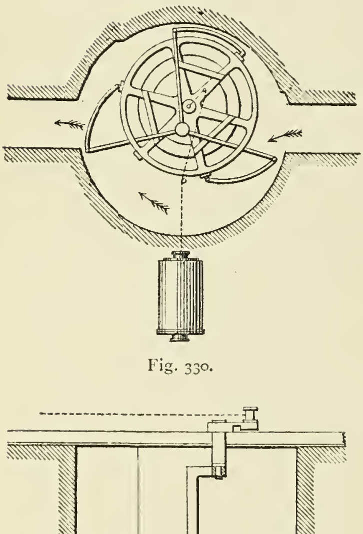


Fig. 330.

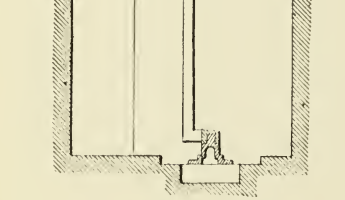


Fig. 331.
The Lemielle Ventilator.

Cooke's ventilator, Figs. 332 and 333, consists of two cylindrical drums, which revolve eccentrically in two cylindrical casings placed side by side. Each drum has a swinging shutter, and this shutter receives its motion from the crank and is so arranged as to be always close to the drum; it thus forms a partition between the outlet and inlet air while the air is being drawn in from the drift leading from the shaft. The drums are placed opposite each other on the

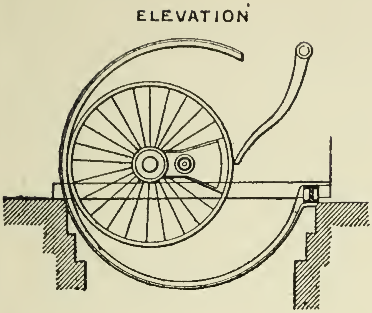


Fig. 332.

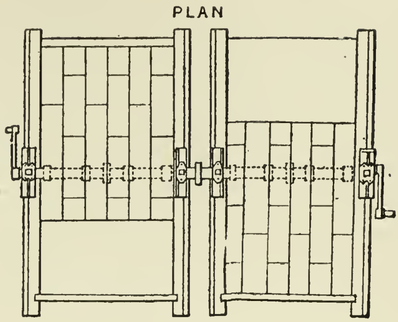


Fig. 333.

Cooke's Ventilator.

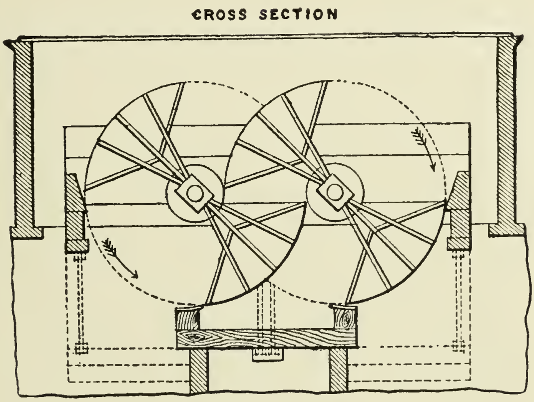


Fig. 334.

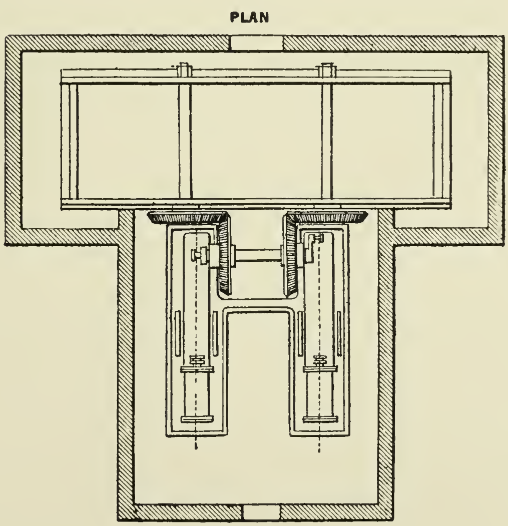


Fig. 335.

Root's Ventilator.

driving-shaft, so that the flow of air is uniform, and that the drums in revolving balance each other. In the Report of the North of England Mining Institute Committee the useful effect of this ventilator working at Hutton Henry Colliery Durham, is given at 37·33.

Root's ventilator, Figs. 334 and 335, is a rotary displacement machine, which may be used to exhaust the air out of a mine, or as an air-compressing machine. It has two rotary pistons of the same size placed on separate shafts, and revolving in a casing having inlet and outlet openings. These may be at the top and bottom or at the sides, but the outlet opening communicates with the atmosphere. The pistons are worked by gearing on the shafts, and they revolve without being in actual contact with each other or the casing, but the clearance between them is only $\frac{1}{8}$th of an inch. They discharge the air in four distinct volumes during each revolution. The engines are placed at right angles to the ventilator, as seen in the drawing. The percentage of useful effect given in the Report previously referred to, for the Root ventilator working at Chilton Colliery, Durham, is 47·84.

The objection to all these varying capacity ventilators is that they are not simple in construction, are liable to be deranged, and (excepting the Struvé) give a low useful effect.

The *Centrifugal* are the most popular of all the ventilators. Early forms of these were Nasmyth's, Brunton's, and Biram's fans, but those now most in use are the Guibal, Waddle, and Schiele, though several others are before the public, one of the most recent being the Capell.

Of these, perhaps the *Guibal*, Figs. 336 and 337, has met with most favour, but all three fans have merits of their own. The Guibal varies from 20 to 50 feet

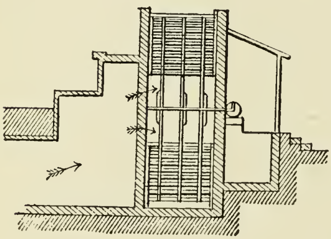


Fig. 336.

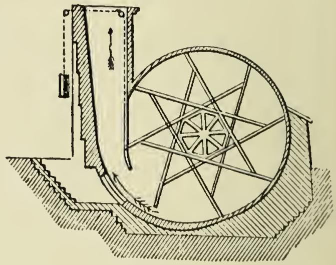


Fig. 337.

THE GUIBAL VENTILATING FAN.

in diameter, it has 8 or 10 blades inclined backwards and curved at the tips. The air can enter at one side or both. The casing is not attached to the fan, but the latter is placed in it. The air is discharged at one particular place through a sliding or adjustable shutter, so that the exit opening may be regulated into an expanding chimney, larger at the top than at the bottom, the effect of which is to gradually reduce the velocity before reaching the outside, where the current is out of the influence of the fan. The sliding shutter allows of the outlet being regulated to suit the volume of air under various circumstances. The most effective opening of the adjustable shutter is ascertained and fixed at any particular colliery experimentally. The percentage of useful effect given in the same Report as quoted before, is 40 for the Guibal ventilator at Hilda Colliery, South Shields, but as 52·95 for that at Pemberton Colliery, Wigan.

The *Waddle*, Figs. 338 and 339, is an open-running fan, because it delivers the air all round the circumference into the atmosphere. For this reason its width is reduced at the periphery, and it is therefore very narrow in proportion to its diameter. The air is received on one side only. The blades are inclined backwards, these and the casing are all in one revolving piece which works completely free of vibration; when well built it forms an extremely compact,

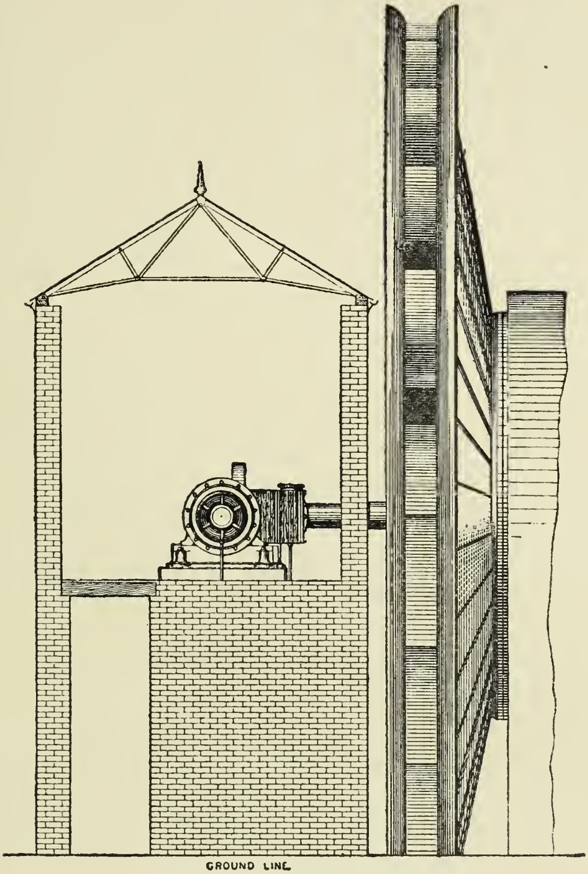


Fig. 338.—The Waddle Ventilating Fan.

rigid ventilator. A high velocity of periphery is obtained by a moderate number of revolutions. The Report of the North of England Mining Institute Committee gives a useful effect of 52·79 for this fan at Celynen Colliery, South Wales.

A 30-feet one at Cwmaman Colliery—when tested in October, 1888, by the combined committees of the North of England, the Chesterfield, and the South Wales Institutes of Mining Engineers—gave a useful effect of 55·8 per cent. and circulated 134,394 cubic feet of air per minute with a water-gauge of 5·53 inches. Mr. Hugh Waddle, the inventor and patentee of the improved fan, Figs. 338 and 339, made by the Waddle Patent Fan and Engineering Co., Llanmore Works, Llanelly, asserts that it utilizes from 15 to 20 per cent. more power than the old

form of fan made by the predecessor of the Waddle Patent Fan and Engineering Co.—viz., the late Mr. J. R. Waddle—and erected at Celynen, Cwmaman, and over 200 other collieries.

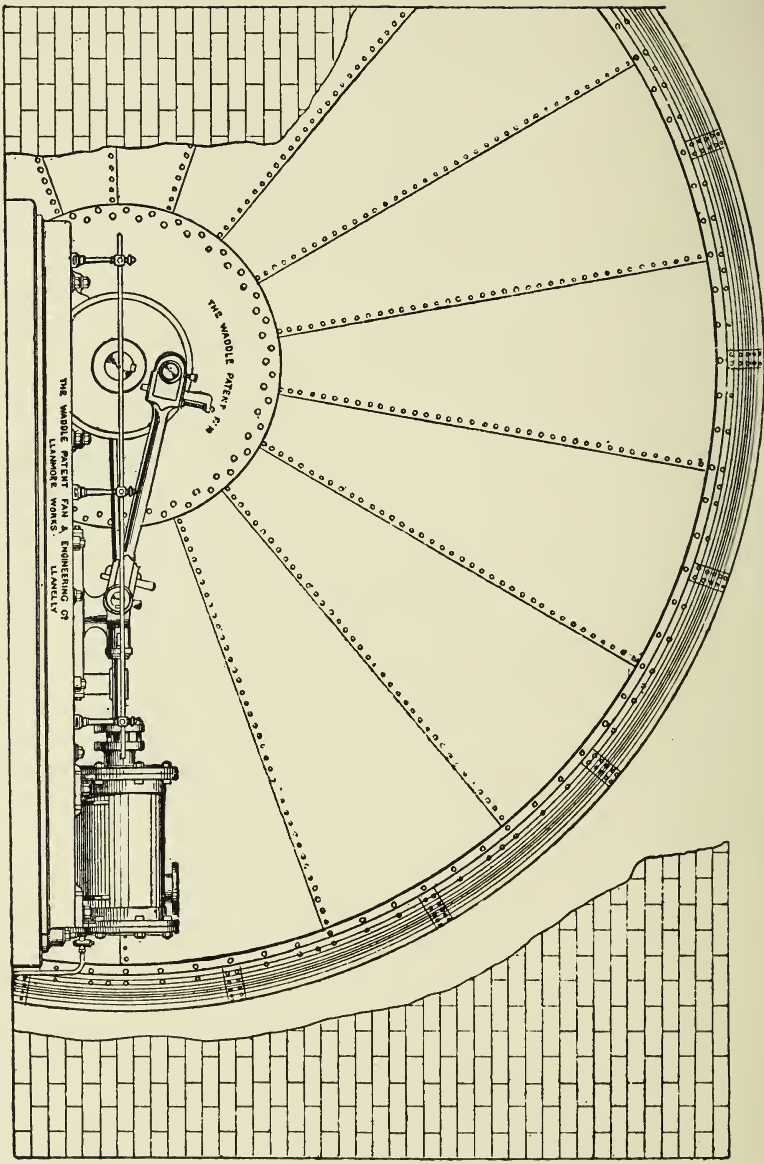


Fig. 339.—The Waddle Ventilating Fan.

The *Schiele*, Figs. 340 and 341, runs fast, the moving part of the fan being small, and constructed wholly in wrought iron, the heaviest portions being disposed round the centre. The disc or blades of the fan taper from the tip, widening towards the centre. This disc revolves between two cast-iron side walls of a

section following the taper of the blades. The air enters at each side of the fan in equal quantities. The casing of the fan is in wrought iron, and takes the form of a gradually increasing volute air-chamber, surrounding the periphery of the blades, and culminating in the exit which forms the widest point of the air-chamber. The object of this is to give a uniformly increasing space beyond the tips of the fan blades, from nothing up to the full area of the discharging aperture.

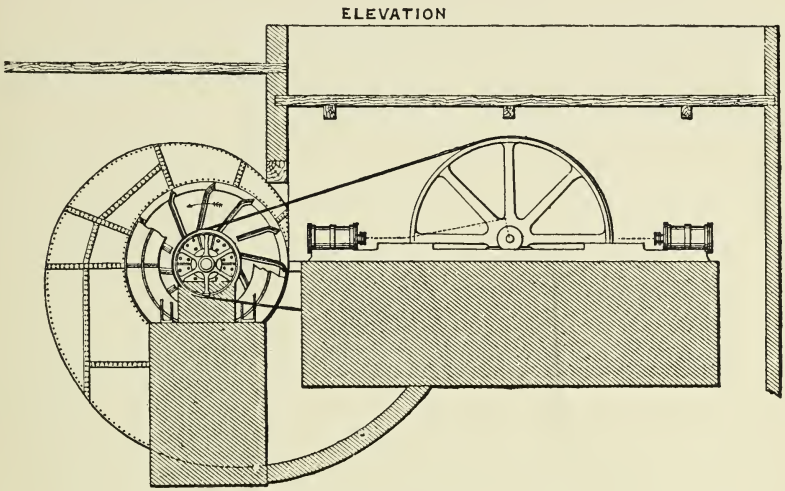


Fig. 340

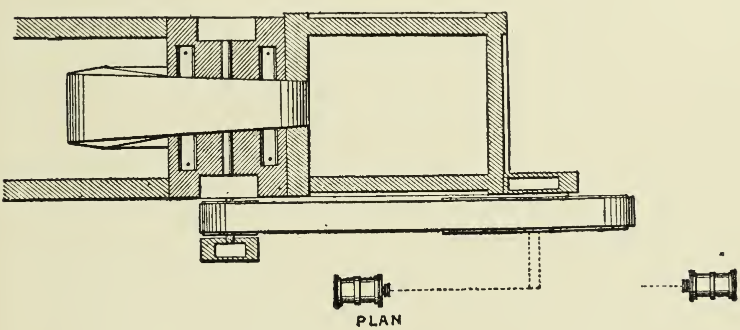


Fig. 341.

THE SCHIELE FAN.

The Schiele, like the Guibal, has an expanding chimney, so that the air is not passed directly into the atmosphere, but, owing to the increased area at the outlet end of the chimney, the air has a gradually reduced velocity, moving up through the chimney more and more slowly until it meets the external atmosphere. Some of the Schiele fans are driven direct from the crank shaft of the engine, but usually the power is transmitted by belting, the engine having a broad fly-wheel for the belt, and another, of small diameter, fixed on the fan shaft. This arrangement is necessary to obtain a proper velocity of fan, with an economical speed of the engine, and, moreover, prevents the shocks of the fan being communicated to the engine, thus resulti

much less wear and tear in the engine. In the report referred to in connection with the other ventilators, the Schiele is said to give 49·27 per cent. of useful effect at Car House Colliery, Rotherham.

The *Capell* fan, as made by the Bowling Iron Co., Limited, Bradford, Yorkshire, is shown at Fig. 342, and is thus described by them :—

The fan is the smallest in the market, and is particularly adapted for moving large volumes of air, where a high water-gauge is required, gauges now being obtained by the Capell fan which some time ago were thought to be impracticable. The highest gauge which has been obtained with the Capell fan is 10 inches. The fans are made either with single or double inlets, to allow the air to pass in on one or both sides, according to the requirements of the mine. It consists of an inner cylinder, in which port-holes are cut, and to this cylinder wings are

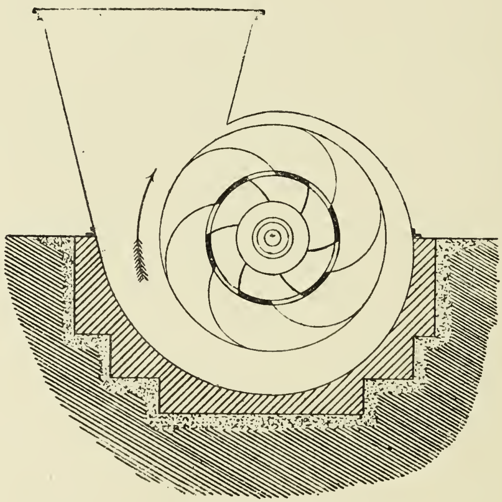


Fig. 342.—The Capell Fan.

attached on both sides, those on the outer side being continued to the periphery of the fan, and the whole revolving on one shaft. The air enters into the cylinder, and escapes through the port-holes into the outer wings, and is carried by them until it is discharged into the *évasée* outlet. The internal cylinder causes no artificial contraction, the sum of the port-hole area being always greater than that of the actual inlet; on the other hand, it appears that the absolute velocity of the air during its passage through the outer wings or chambers remains all but unaltered. The work performed by the Capell fan in comparison with the energy used in driving it, is remarkably high, and has reached as much as 80 per cent. of the power developed by the engine. This necessarily implies economy of steam power, and a smaller engine than is necessary for driving fans of less efficiency. Further, the fans being comparatively smaller than any other, to give the same efficiency, less expense is incurred in outlay on foundations, whilst the use of the plated case and *évasée* chimney when protected from the weather by suitable covering has been found preferable to brickwork.

The material used in the construction of these fans is of the highest quality of Siemens' mild steel. The shafts are of either forged or compressed steel, the

suspensory arms and minor forgings being of Lowmoor or Bowling iron, and Siemens steel castings are used for attaching the fan centre to the shaft. Special care is taken to provide long bearings for the shaft, in order to ensure cool running.

SINGLE-INLET ENCASED FANS.

Diameter.	Width.	Revolutions.	W. G.	Volume in cubic feet per minute.	H.P. in Air.	I.H.P.
FT. IN.	FT. IN.					
8 0	4 0	300	2·5	50,000	20	30
10 0	4 6	240	2·5	75,000	30	45
12 0	5 4	210	2·5	100,000	40	60
12 6	5 8	210	2·5	125,000	50	75
15 0	6 6	180	2·5	150,000	60	90

DOUBLE-INLET ENCASED FANS.

Diameter.	Width.	Revolutions.	W. G.	Volume in cubic feet per minute.	H.P. in Air.	I.H.P.
FT. IN.	FT. IN.					
8 0	7 0	300	2·5	100,000	40	60
10 0	8 6	240	2·5	150,000	60	90
12 0	10 0	210	2·5	200,000	80	120
12 6	11 6	210	2·5	250,000	100	150
15 0	11 6	180	2·5	300,000	120	180

The above fans will, in all cases, give a greater volume and W. G. at a higher speed; or a greater volume at a lower W. G. at the same speed; or a higher W. G. at a reduced volume at the same speed.

These tables are useful as indicating the capabilities of the fans, but the actual figures in the last four columns for any colliery can only be ascertained experimentally. A fan working at a certain number of revolutions and yielding a certain result at a colliery, will probably yield a different one when working at the same speed at another. Again, the conditions under which it works at the same colliery vary from year to year as the workings are extended, and the air-courses lengthened or altered.

ENGINES FOR DRIVING CAPELL FANS, MANUFACTURED BY THE BOWLING IRON CO., LIMITED.

I.H.P.	Diameter of Cylinder.	Stroke.	Ratio of Pulleys.	No. of Revolutions.
30	10	24	3 : 1	100
45	12	24	3 : 1	80
60	14	30	3 : 1	70
75	16	30	3 : 1	70
90	18	36	3 : 1	60
120	20	36	$3\frac{1}{2}$: 1	60
150	22	36	$3\frac{1}{2}$: 1	60
180	24	48	4 : 1	50

The above engines are calculated at 60 lbs. boiler pressure, and they are supplied either for rope or belt gearing.

The following is a recent experiment made with the Capell fan at the Carlton Iron Co.'s East Howle Colliery, Ferry Hill:—The fan is 12 feet in diameter and 10 feet wide, with double inlet capable of passing, at 210 revolutions, 200,000 cubic feet of air per minute, with a 3-inch water-gauge. Engines, a pair of horizontal cylinders 20 inches in diameter and 36-inch stroke, running 4 to 1. Engine, 50 revolutions; fan, 200 revolutions; W. G., 3·3 inches; air, 156,510 cubic feet; mean pressure, 20·2 lbs.; spring, 1/30; H. P. in steam, 114·4; H. P. in air, 81·35; useful effect, 71·36 per cent.; equivalent orifice, 31·6 square feet; theoretical W. G., 7·1 inches; manometrical effect, 46·5 per cent.; output of fan, 78·2 cubic feet = 71 per cent.

If these figures are thoroughly reliable, the Capell is a most efficient mine ventilator, and must win its way to popularity.

We are informed that Mr. Stephen Humble, of 5, Westminster Chambers, Victoria Street, London, has recently patented an improved Capell mine ventilator. Colliery managers and others interested in collieries will be much interested in trials and figures connected with experiments of this new fan.

Mr. Arnold Lupton has patented a fan in which he has endeavoured to combine the best qualities of other fans. It is called the *Medium* fan, being made of a size between the Waddle and Guibal on the one hand, and the Schiele and Capell on the other. It is a compound of the Waddle and the Guibal. The results of experiments showing the capabilities of this fan are awaited with much interest.

The principle on which all centrifugal fans act is this:—When the fan revolves the centrifugal force drives the air from the centre, which tends to create a vacuum, and air rushing in to take its place, a current is produced. In general, ventilators are used to exhaust the air, and are, therefore, placed at the top of the

upcast shaft, but they are capable of being used as forcing or compressing machines, in which case, of course, they would be placed at the top of the downcast. The object to be attained, whether by furnace or a machine, is to make the two columns in the upcast and downcast of different densities, the difference in the weight of the two columns of air of the same height forming the ventilating pressure. Where a shaft, with a fan working on it, is required for winding as well, it is necessary to have some covering over the top of the shaft, to prevent the entry or exit of air. For this purpose, covers are placed over the shaft, one of which is lifted when the cage ascends, the cage itself then filling up the opening. When the distance between the fan drift and the pit top admits of it, another plan is to place two sets of doors in this space, and arrange these so that the cage on leaving the surface opens the lower doors, at the same time closing the upper, and, on coming to the surface, it opens the upper doors and closes the lower.

It is desirable in most cases, and indispensable in very fiery collieries, for a ventilating machine to have two separate engines, either of which would be capable of working it, and these engines should be placed on opposite sides of the fan. The object of this is to provide a second means to work the ventilator in case of an accident to the first. A better plan is to have a duplicate fan and engine connected with the fan drift, so that if an accident occur, either to the fan or to the engine, the ventilation of the colliery would be ensured. In such a case each engine and fan could be worked alternately, for a week or fortnight at a time, so as to maintain them in good working order.

Fans of the Guibal and Waddle class, with high periphery speed resulting from a few revolutions per minute, have engines coupled direct, but small fans, like the Schiele or Capell, must make more revolutions per minute than the others to get a high circumferential velocity, and these are usually driven by broad straps, and the engines may be geared to suit the speed required. These small fans make from 100 to 300 revolutions per minute, and a fan-engine should not have a greater piston speed than 250 feet per minute. The most effective engines work expansively, and are condensing, and compound engines are the most economical in working.

As regards the economy or efficiency of furnaces, much depends on the depth of the upcast shaft, but with fans the depth is not an element requiring consideration. Besides being in every case a much safer and steadier means of producing ventilation, fans undoubtedly give better results in shallow mines. No doubt a furnace can be advantageously applied in a deep, dry shaft, the bottom of which is considerably below the bottom of the downcast. If, however, the mine be fiery, as most deep mines are, a fan should be used to produce the ventilation, and in arranging the upcast and downcast pits the air should be made to descend that sunk to the lowest level, and by what is called "ascentional ventilation" pass into each district. This is the most natural, and also the safest, means of ventilating, for the currents, on becoming warmer by their passage through the mine, are more easily carried up-hill than down, and, moreover, the gas is much more readily carried away with ascentional ventilation.

As the air, if allowed to follow its own course, would go by the easiest and shortest route, from the downcast to the upcast, the different currents must be guided by stoppings and doors into the various divisions of the mine. With a downcast 15 feet in diameter, giving an area of 176·715, there might be five separate currents branching off, each 35 feet in sectional area, without any increase in velocity. The benefits of thus splitting the air may be briefly stated. The same ventilative power will produce a larger volume of air by splitting than by carrying one body or current of air from the downcast round the workings to the upcast. Each district is supplied with fresh air, which comes from the downcast

and returns to the upcast quite independently of the other currents, so that each is thus rendered purer and pleasanter for the workmen.

But as it almost invariably happens that the lengths of these air-currents are unequal, the air if allowed to take its own course would not flow in equal quantities into each division, or in such other proportion as from the circumstances of each district may be desirable. If left to itself the shortest air-course would probably get the largest share of the air; but there are other circumstances, such as sectional area and rise or dip workings, which would affect the quantities flowing into each district. To balance these splits, if they are very unequal, regulators are fixed, in such a way that we can enlarge or diminish the aperture, through which the air passes, at pleasure. Usually this is done by means of a sliding door which moves horizontally in a groove in the wooden framing. Sometimes the door slides vertically, but whichever way it moves it should be kept locked in its proper position, by a properly appointed person. It does not matter whether these regulators are placed in the intake or return airway, so far as regards restricting the passage for the air, but as they would form obstructions in the intakes which are used generally for haulage, they are placed in the return airways. The amount of opening for the passage of air is determined by the circumstances of the mine, and the relative quantities desired for each district.

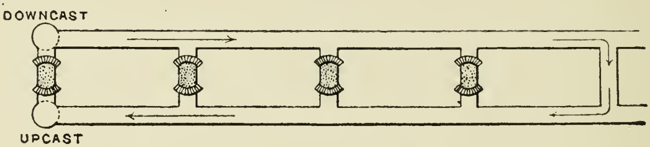


Fig. 343.—Permanent Stoppings in Fiery Mines.

The stoppings used to prevent the air from being diverted from the desired course are variously constructed. For a non-fiery mine it may be found sufficient to build a brick or stone wall across the mouth of the road leading out of that intended for the main air-course and to back it up with rubbish to prevent leakage. In the case of fiery mines, however, these stoppings cannot be too strongly built, as they may possibly have to resist the effect of an explosion, and it must be remembered that a blown-out stopping allows the intake air to return through it to the upcast shaft. The best stoppings have two walls 15 or 20 feet apart, each with a curved outline, the convex sides of which are presented outwards and the space between the walls filled closely with stone or rubbish: see Fig. 343.

If only stoppings were built strong enough to resist the force of an explosion of firedamp, the air-currents, unless stopped by falls, would still flow into the workings after the explosion, and many lives might thus be saved which would otherwise be lost through the afterdamp. Occasionally it is necessary to have a travelling road through some of these bye-roads, and it is then impossible to have the way bricked up altogether. Doors of course must be fixed in such cases, but as it is impossible for these to resist the effects of an explosion they should be avoided if possible. Where they must be put, they should have considerable attention paid to their design. If only required for travelling through, the frame should be set in masonry and the doors hinged from the top and open towards the intake side. This will ensure their falling to, despite of any want of thought on the part of the person passing through, and if instead of being placed vertically they form an angle of 70° or 80° with the floor, they will remain closed, the force of the intake air helping to keep them firmly in that position. Where the road has to be used both for travelling and the passing of tubs, a different kind of door is required so as in opening to allow the horse and tubs to pass. The framing of such doors should not be set quite upright, but sufficiently inclined for the door

to fall and close by its own weight. A boy is stationed near to open it as required. Two similarly constructed doors or more should be used between all main intake and return airways, and wherever the escape of air during the passing of the tubs is important, they should be placed at such intervals apart as to allow of the train or set of tubs and the horse to be between them, to prevent the two doors from being open at the same time. In fixing these doors care should be taken to make them airtight at the different joints and spaces behind the framing. Safety-doors are sometimes fixed in the roof, so that in the event of an explosion blowing the ordinary doors away, these safety-doors may fall into use or be dropped as soon as possible and so take the place of the others.

It is often necessary to take one current of air over or under another. Usually the "returns" are taken over the "intake," and this is done by means of an air-crossing or air-bridge. In fiery mines these should be made so strong as to resist the effects of an explosion, and the better plan is to pass the return below the intake. In all explosions there is more force exerted in the intakes than returns, and it often happens that an arch of a crossing is lifted up and blown away. Wherever practicable the intake and return should be separated by some feet of solid rock. Fig. 344 shows an air-crossing suitable for a fiery mine. A great deal of care must also be taken in fiery mines to keep the brattice well up to the face of the workings, and if the brattice does not equally divide the road the smaller side should be the intake. The brattice usually consists of canvas nailed to the posts and divides the road into two equal divisions vertically, providing one of such divisions is large enough for the passage of the tram or tub, or if not, one division is made wider than the other. Brattice may also be made by nailing boards to the posts, and for a more permanent brattice in the case of a stone drift to be driven a considerable distance a division is formed by building a brick brattice.

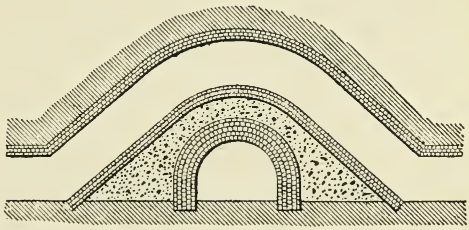


Fig. 344.—Air-crossing.

As to the velocity at which the air is taken along the roads much will depend upon the circumstances, but it is always desirable to have large air-courses, and as each split of air must have from 5,000 to 6,000 cubic feet per minute, and perhaps more, there would be in a road 6 feet by 5 feet or 30 feet area a velocity of $\frac{6000}{30}$ = 200 feet per minute for the latter quantity. There is no inconvenience in such a velocity, but if the same quantity of air were taken along an extremely small road the velocity would be unpleasant to those traversing it. A velocity of from 100 feet to 300 feet per minute is both safe, convenient, and economical. At some collieries the main airways are swept by current velocities of 1,200 feet per minute. If an ordinary Davy lamp be used at the colliery 300 feet per minute is the extreme velocity the air should travel at in the return air-courses, where the air is mixed with firedamp to a dangerous degree, because the flame of an ordinary Davy lamp will pass the gauze in a current of 6 feet per second, and it would not be safe to use such a lamp in currents approaching the explosive point. In shafts, in the main intake and return airways, the velocity cannot in practice be kept so low as in the further parts, because the former are necessarily limited in number. From 900 to 1,000 feet per minute is a fair velocity for the air to travel at in the shafts, and generally if it is required to pass from 150,000 to 200,000 cubic feet per minute, the diameter of the shaft should be not less than 14 feet.

There is a difference of opinion as to whether the upcast or downcast should

be the larger. Owing to the expansion of the air, the volume ascending the upcast would require more area than the downcast, if the same velocity were maintained in the two shafts. But there is no absolute necessity for this, and the velocity of the air may be much higher in the upcast shaft. Irrespective of areas, it is more important that the upcast shaft be on the rise side of the downcast, but in the case of two shafts of equal depth whose surface levels are the same, a slight advantage will be derived from making the shaft whose area is least the downcast so that the velocity of the air may be the same in each shaft. Other considerations may, however, suggest a different arrangement; for instance if a furnace were used, the larger shaft being wet, and the smaller one dry, the circumstances point to the advisability of making the larger shaft the downcast. Again, where a furnace is used, there may be wire ropes or tubbing that the smoke of a furnace would injure in the one shaft and not in the other, so that in making a decision as to which shaft shall be the upcast, the particular circumstances of the case must be well considered.

Experiments have been made with fans worked by compressed air placed underground at long distances from the bottom of the shaft. The object of these fans is to assist the main or general ventilating power. Where there are far-off splits otherwise difficult to ventilate, these auxiliary fans give good results and increase the total quantity of air circulating.

The usual method of ascertaining the quantities of air in mines is by the use of the *Anemometer*—an instrument for measuring the velocity of the air. The wind gives the vanes of the anemometer a speed proportional to that of the current, and the number of revolutions is registered upon the face of a dial fixed on the central part of the instrument. Biram's anemometer is the one in general use, and in it each revolution of the vanes corresponds to one foot in the linear motion of the air. To get the number of cubic feet passing per minute, multiply the velocity per minute, or in other words the recorded revolutions per minute by the sectional area of the airway. A slight correction should, however, be made owing to the friction of the anemometer. The rule generally used to find the true velocity is $v = \cdot 97\ \mathrm{R} + 40$ nearly, where $v =$ the true velocity and R the recorded number of revolutions per minute.

Another method of air measuring formerly practised in mines worked with naked lights, but now seldom used, consists in exploding a small quantity of gunpowder and noting the time the smoke takes to traverse a certain distance, from which the velocity of the air is ascertained. The method of holding the anemometer is worthy of remark, as different results may be obtained in the same airway owing to the difference in the velocity of the current at different parts of the airway. It should be held at arm's length in front of the body, the vanes should be kept square with the current of air, and the anemometer should be slowly moved uniformly over the whole area of the airway from a point near the floor to a point near the roof. Several trials should be made in the same place and the average result taken. In large airways and fan drifts, where the greatest accuracy may be required in testing the efficiency of fans, the most correct method is to fix fine wires or strings across the road from side to side and from floor to roof, at regular distances apart, the one set of strings being placed at right angles to the other, so as to divide the airway into a number of even divisions, and then to note the revolutions of the anemometer during 1, 2, or 3 minutes at each division. The mean of these are taken. But the operation should be repeated in cases where great accuracy is desired, and if the mean result differs materially from the first mean result, it will be necessary to go through the operation again, and perhaps again.

The *Thermometer* is a measurer of temperature, mercury being used for

ordinary temperatures. It depends for its action on the fact that all bodies with the rise and fall of their temperatures expand and contract. It consists of a glass tube closed at the top, with a bulb at its bottom end, and having mercury placed in it. A scale of degrees is fixed to the tube. As used in mines the thermometer registers the temperature of the air, and we are able to measure the difference of temperature between the air in the downcast and upcast shafts or at any desired point in the workings.

Thermometers are graduated according to three scales, viz., Fahrenheit's, which is that commonly used in England; the Centigrade scale, which is that generally used in the scientific world; and Reaumur's scale, which is that taking its name from a French philosopher, who constructed his thermometer with alcohol of such a strength that 1,000 parts at the freezing point of water became 1,080 parts at its boiling point.

On Fahrenheit's thermometer 32° indicates the freezing point and 212° the boiling point of water, and the space between these two fixed points is divided into 180 even divisions; these even divisions are produced above and below 32° and 212°.

In the Centigrade thermometer 0° indicates the freezing point and 100° the boiling point of water, the space between these two points being divided into 100 even divisions. In Reaumur's 0° indicates the freezing and 80° the boiling point of water, the space between these two points being divided into 80 even divisions. It is plain therefore that—

$$180^\circ \text{ Fah.} = 100 \text{ Cent.} = 80^\circ \text{ Reaum.}$$

and therefore $1^\circ \text{ Fah.} = \frac{5}{9} \text{ Cent.} = \frac{4}{9} \text{ Reaum.}$

To transfer Fahrenheit degrees to the other scales, we must first subtract 32°, in order that the number of degrees from the freezing point may be ascertained. These multiplied by $\frac{5}{9}$ths will give the equivalent number of Centigrade, and by $\frac{4}{9}$ths the equivalent number of Reaumur degrees.

To reduce Centigrade and Reaumur degrees to the Fahrenheit scale, multiply by $\frac{9}{5}$ and $\frac{9}{4}$ respectively and add 32°.

If the temperature be below the zero in any of the scales, a minus sign (—) is placed before the number thus: —5° Fah. means 37° below freezing point.

The following examples may be tested:—

Fah.		Cent.		Reaum.
190°	=	$87{\cdot}\dot{7}^\circ$	=	$70{\cdot}\dot{2}^\circ$
155°	=	$68{\cdot}\dot{3}^\circ$	=	$54{\cdot}\dot{6}^\circ$
128°	=	$53{\cdot}\dot{3}^\circ$	=	$42{\cdot}\dot{6}^\circ$
3°	=	$-16{\cdot}\dot{1}^\circ$	=	$-12{\cdot}\dot{8}^\circ$
-15°	=	$-26{\cdot}\dot{1}^\circ$	=	$-20{\cdot}\dot{8}^\circ$
-40°	=	$-40{\cdot}^\circ$	=	$-32{\cdot}^\circ$

It must be borne in mind that a thermometer does not give the absolute expansion of the mercury, but the difference between the expansion of the mercury and that of the glass. Mercury expands about 7 times more than glass.

The *Barometer* is an instrument used for measuring the pressure of the air. If a glass tube a yard long and closed at one end be filled with mercury and inverted with the finger placed over the open end until that end be placed in a vessel containing mercury and then removed, a part of the mercury will run out, but the tube remains filled to a height of about 30 inches above the surface of the mercury in the vessel. That is, the ordinary pressure of the atmosphere is sufficient to balance a column of mercury 30 inches high. But the pressure of the atmosphere varies in this country between 28 and 31 inches of mercury. The barometer has a scale and a sliding vernier fixed to it, by means of which it

may be read to the $\frac{1}{100}$th part of an inch. In a former part it was stated that the average atmospheric pressure was sufficient to balance a column of water nearly 34 feet high, and as mercury is 13·59 times heavier than water, it is consistent that it should balance a column of mercury 30 inches high, for $\frac{34 \times 12}{13 \cdot 59} = 30$ inches. The barometer is of service in showing atmospheric changes. The issue of fire-damp from the goaves and working faces of the mines is checked when the barometer is high, and liberated rather more freely when the barometer is low. A consideration of the difference of the quantity of gas yielded under the two extremes of the barometer is not so important, however, as the result following from a falling barometer, because the escape of fire-damp is facilitated when, after the barometer has stood steadily at a high or moderately high reading for some days, it is succeeded by a rapid and sudden fall. The gas under those circumstances issues more freely from the coal, and also owing to the reduced pressure it finds its way out of the goaves into the roads; it is important therefore to exercise increased vigilance in fiery mines during a falling barometer, whether it stood high or not before it began to fall. Numerous cases are recorded where the airways of mines were found to contain large quantities of fire-damp with a steady barometer of long continuance, though the airways were a short time previously clear of the gas at the same indication of the barometer. This has been followed by a falling barometer, proving that the fire-damp of our mines is more sensitive to atmospheric changes than the barometer, as indeed might have been expected—gas being such an attenuated, mobile and highly elastic fluid. The lesson to be learned from this is, that while we duly appreciate the barometer and go to it continually for its readings, we do not rely solely on it, but continue our examination with extreme caution to the innermost recesses of the mine, ever on the alert for every change.

When the barometer is at 28 inches, the pressure of the air per square foot is about 1,979 lbs., and when at 31 inches it is about 2,191 lbs. To find the theoretical quantity of gas that would be given off from each 1,000 cubic feet of space in the gas-charged goaves of a fiery mine due to a fall of the barometer from 31 to 28 inches:—$31 - 28 = 3$ inches difference. Then as 31 : 3 :: 1,000 : 96·77 cubic feet. So that if the goaves could be measured and were found to contain 10,000 cubic feet, there would be $96 \cdot 77 \times 10 = 967 \cdot 7$ cubic feet of fire-damp given off by them. The cubic contents of goaves cannot be measured with any degree of certainty, however, and any estimate of goaf contents must be based on the superficial area over which the goaf extends and an assumption of a certain percentage of it being more or less open. The amount of goaf present in some old collieries necessitates the greater caution in observing and noting the changes of the barometer.

Atkinson, in his *General Principles of Ventilation*, says:—" In ordinary states of the weather mercury is about 10,800 times as heavy as the same volume of air near the surface of the earth, and hence about 900 feet of ascent or descent makes a change of 1 inch of mercury in the height of the barometer." Again, " The air at the surface of the earth is generally pressed by the whole of the air above it, to an extent measured by 29·922 inches of mercury (reckoned at the density due to melting ice 32°), as shown by our common barometers; a pressure equal to 2,116·4 lbs. per square foot. To give this pressure we should require the air of the atmosphere to be 26,216 feet high, if it was all as heavy as the air at the earth's surface."

In forming a rule to meet the fluctuations of the barometer, take this 26,216 feet as being the height of the atmosphere at sea level, which gives its appreciable weight or pressure on the earth's surface.

Then for pits on the datum line of sea level will be obtained the following rule to find the height of the mercurial column corresponding to shaft depths.

$I = \frac{D \times B}{26{,}216}$, where I = inches of mercury due to the shaft depth; D, depth of shaft in feet; and B, height of barometer at the pit top. The barometer reading at the pit bottom will then be the reading at the top + I, or in case where the height of the barometer is given at the top and bottom of a pit whose depth it is desired to know, and where I represents the difference of the two barometer readings, $D = \frac{26{,}216 \times I}{B}$.

Supposing a question like the following has to be answered. The barometer at the top of a shaft is 30·2 inches, the thermometer is 65° F., the depth of the shaft is 1,100 feet, and the thermometer stands at 75° F. at the pit bottom, say what is the difference in the pressure of the air at the top and bottom of the shaft, and the difference in the reading of the barometer.

Here $I = \frac{1{,}100 \times 30 \cdot 2}{26{,}216} = 1 \cdot 267$. Therefore the reading of the barometer at the pit bottom is 30·2 + 1·267 = 31·467. To get the weight of a cubic foot of air at the shaft top by Atkinson's formula, $\frac{1 \cdot 3253 \times 30 \cdot 2}{459 + 65} = \cdot 0763814$ lb. Similarly, $\frac{1 \cdot 3253 \times 31 \cdot 467}{459 + 75} = \cdot 078096$ lb. as the weight of a cubic foot of air at the shaft bottom.

Hence, ·078096 − ·0763814 = ·0017146 lb. difference in the weight per cubic foot of the air at bottom and top of the shaft.

The *Water-gauge* is a very simple instrument, and consists of a glass tube bent like the letter U, both ends of the tube being open. A little water is placed in the bend of the tube, which forms the bottom part of it. A sliding scale of inches and decimals of an inch is attached to it. At the top of one arm of the tube is placed a nose piece, by means of which it is passed through a door, and, by so doing, one side of the tube is placed in contact with the air on one side of the door, and the other is exposed to the influence of the atmosphere or air current at the other. Where a difference of atmospheric pressure exists, such as would be between the intake and return currents of air near the shaft, or between a fan drift and the outside air on the surface, the water is depressed in one side of the tube and raised in the other. The scale of inches and decimals shows the difference of level in the tubes. The instrument is used thus to show the force of the air current generated whether by furnace or fan.

The weight of a cubic inch of water being ·036 lb., if the water-gauge read 1 inch the pressure is ·036 lb. per square inch, or ·036 × 144 = 5·184 lbs. per square foot; usually taken at 5·2 lbs. per square foot. For any other reading of the water-gauge, multiply 5·2 lbs. by that reading to find the pressure per square foot. Thus, ·5 on the water-gauge = ·5 × 5·2 = 2·6 lbs. pressure per square foot. The water-gauge acts as a check on the state of the air courses. When they remain in the same state over, say, two days, and the ventilating power is not increased or lessened, the water-gauge on the second day in each position of trial should, under ordinary circumstances, read the same as on the first, and, if not, it would probably be owing to a fall in some aircourse or aircourses which had increased the friction.

It will be well here to consider some of the rules for working out problems connected with furnaces and fans as used for motive powers.

The power obtained by furnace ventilation is measured by the difference between the weight of the air in the downcast and upcast shafts. The length of column in the downcast, which would be equal in weight to the difference of the

weight of the air in the two shafts, is called the motive column, to find which use the following formula:—

Let M = Motive column in feet.
„ T = Average temperature of air in the upcast.
„ t = Temperature of the air in the downcast.
„ D = Depth of the downcast in feet.

$$\text{Then } M = D\,\frac{T-t}{T+459}.$$

If the depth of upcast and downcast were each 300 feet and were 12 feet in diameter, or had 113 feet superficial area, the temperature of the downcast 60° F. and the average of that in the upcast 150° F., the motive column would be $300 \times \frac{150-60}{150+459} = 44{\cdot}33$ feet, that is, the air in the downcast would balance the air in the upcast with a column 44·33 feet shorter than that in the upcast.

From the formula already given to find the weight of a cubic foot of air at any temperature, and under any pressure, if the barometer read 30 inches, to find the weight of a cubic foot in the downcast, $\frac{1{\cdot}3253 \times 30}{459+60} = {\cdot}0766$ lb., and this multiplied by the depth in feet and by the area thus, $\cdot0766 \times 300 \times 113 = 2{,}596{\cdot}74$ lbs. the total weight in the downcast. For the upcast, $\frac{1{\cdot}3253 \times 30}{459+150} = {\cdot}06529$ lb., the weight of a cubic foot and multiplied by 300 and by 113 = 2,213·34 lbs. as the total weight in the upcast. 2,596·74 − 2,213·34 = 383·4 lbs. as the difference in weight in the two shafts. Therefore to find the motive column, as 2,596·74 : 300 :: 383·4 : 44·3 as given before. If the quantity of air circulating were 150,000 cubic feet per minute, proceed to find the horse-power exercised by the furnace thus:—The weight of a cubic foot of air in the downcast being ·0766 lb. at the bottom of the pit, there would be a pressure of $\cdot0766 \times 300 = 22{\cdot}98$ lbs. due to its mere weight. In the upcast the weight would be $\cdot06529 \times 300 = 19{\cdot}587$ lbs. and $22{\cdot}98 - 19{\cdot}587 = 3{\cdot}393$ lbs. as the difference of pressure on each square foot of area. Therefore $\frac{150{,}000 \times 3{\cdot}393}{33{,}000} = 15{\cdot}4227$ horse-power.

Some authorities use the formula $M = D \times \frac{T-t}{t+459}$ which gives the length of motive column in feet of air of the temperature in the upcast, and this formula will give the same pressure in pounds per square foot as $M = D \times \frac{T-t}{T+459}$ which gives the length of motive column in feet of air of the temperature of the air in the downcast, but the former gives also the theoretical velocity, viz., $v = \sqrt{2\,g\,M}$, with which the air would escape from the upcast neglecting friction. Applying this formula to the foregoing example $M = 300 \times \frac{150-60}{60+459} = 52{\cdot}02$. Or, taking the total weight as before, worked out in the downcast at 2,596·74 lbs., and in the upcast at 2,213·34 lbs., with a difference between the two of 383·4, the motive column in feet of air of the temperature of the upcast may be found by proportion thus:—As 2,213·34 : 300 :: 383·4 : 51·97, as before, except a slight difference owing to the loss of decimal places.

The simplest way of getting the difference of pressure on each square foot of area between the upcast and downcast is by using the water-gauge. If this had been tested at the separation doors between the upcast and downcast shafts in the case just given, it would have read about ·65″, because $5{\cdot}2 \times {\cdot}65 = 3{\cdot}38$ lbs., as will be understood by reference to the remarks on the water-gauge.

This head or motive column may be easily converted into inches of water, as shown in the water-gauge. The motive column is always expressed in feet, and as the weight of a foot of air at 60° F. is 0·0766 lb., and that of an inch of water is 0·036 lb., this gives a pressure of $\cdot 036 \times 144 = 5\cdot 184$, but, as before stated, usually taken at 5·2 lbs. per square foot; therefore multiply this motive column by ·0766 ($= \cdot 0766 \times 44\cdot 3 = 3\cdot 393$ lbs.), the pressure of a foot of air, and divide the product by 5·2 lbs., the pressure of an inch of water, to find the indication of the water-gauge. $\frac{3\cdot 393}{5\cdot 2} = \cdot 652$. Or, what is the same thing, divide the motive column at once by 68 to find the water-gauge, because $\frac{5\cdot 2}{\cdot 0766} = 68$ nearly. Taking then the motive column at 44·3 feet in the case being considered, the water-gauge would read $\frac{44\cdot 3}{68} = \cdot 6514$.

Or, if the motive column had been expressed in feet of air of the temperature of the air in the upcast, a foot of air at 150° F. as shown, weighs ·06529 lb., and if the motive column of 52·02 feet be multiplied by ·06529 lb., the pressure of a foot of the air, and the product be divided by 5·2, thus $\frac{52\cdot 02 \times \cdot 06529}{5\cdot 2}$, the result is the water-gauge = ·653, which is almost the same as before, proving that the pressure in pounds per square foot is the same whichever formula is used.

To find the horse power of ventilation then multiply the pressure per square foot (which may be ascertained by multiplying the water-gauge in inches by 5·2) by the cubic feet of air passing per minute, and divide by 33,000.

The ventilating pressure is chiefly required to overcome the resistance due to friction and obstruction, that required to put the air in motion being very slight. If that pressure be expressed as a head of air or motive column, the velocity due to the pressure will be equal to that which a body would acquire when it had fallen through a height equal to the head. A column of air 1 square foot in section and 13·09 feet high, weighs 1 lb., and will therefore exert a pressure of 1 lb. to the square foot. This pressure produces a velocity in the air current equal to that which would be attained by a falling body through a height of 13·09 feet. This is usually expressed by the well-known formula for gravity, $V^2 = h\ 2\ g$, whence $V = \sqrt{h \times 2\ g}$ in which V is the velocity in feet a second, h, the height or space in feet fallen through, and g, the velocity in feet acquired by a falling body at the end of one second of time, the value of which is 32·2. Thus $V = \sqrt{h \times 64\cdot 4} = 8\cdot 02\ \sqrt{h}$, and therefore $h = \frac{V^2}{64\cdot 4}$.

If the air current has a velocity of 4 feet per second, the head required to produce this velocity (omitting all consideration of friction) would be calculated thus, $h = \frac{4^2}{64\cdot 4} = \cdot 2484$ foot, or expressed in inches of water-gauge $\frac{\cdot 2484}{68} = \cdot 00365$. Strictly speaking, this value should be added to that found for frictional and other resistances in mines, but when it is noted how very small is the pressure required to produce the velocity, and also the fact that the resistances are only estimated approximately, it is not surprising that the pressure to produce the velocity is in practice neglected, and the calculations rendered easier by such neglect.

The economy of a fan is often judged of by what is called its useful effect. This simply means the proportion that the power of ventilation bears to the horse-power exercised by the engine in driving the fan. Thus, suppose the horse-power of a fan-engine to be 100, and the horse-power of ventilation to be 50, we say that the useful effect of the fan is 50 per cent. Where it is desired to work out

questions as to the useful effect of ventilating fans, it is necessary to be very exact in all data, or the results are misleading. Thus, the air must be very carefully and accurately measured at a point near the fan inlet, as explained under remarks on the anemometer. If it is desired to calculate the useful effect on the volume of intake air, a correction will have to be made for pressure and temperature, as the volume of air in the fan drift will be increased as compared with its state at the intake owing to different barometer and thermometer readings. That is, supposing in the ventilator drift the barometer reads 30 inches and the temperature shows 70° F., whilst the readings are 31 inches and 40° F. respectively at the intake airway. Then for every 1,000 cubic feet per minute in the intakes, the volume it would occupy in the ventilator drift will be found by the formula already given thus, $1{,}000 \times \frac{31 \times (70 + 460)}{30 \times (40 + 460)} = 1{,}095\cdot\dot{3}$ cubic feet. Then as $1{,}095\cdot\dot{3} : 1{,}000 ::$ quantity in fan-drift : intake quantity.

Again, very accurate diagrams must be taken with the steam indicator (of which more will be said hereafter) on both sides of the piston, and these should be made simultaneously with the air measurements, and in calculating the horse-power of the engine allowance must be made for the area of the piston rod, whether on one or both sides of the piston, as the case may be. Any natural ventilation operating with or against the fan should be carefully ascertained and allowed for. As it is evident that *all* the horse-power of the engine is not used for driving the fan, but a part is required to overcome its own resistances, these should be ascertained by disconnecting the engine from the fan, and diagrams taken of it when running at the same speed as when working the fan. Suppose it be required to find the useful effect of a fan when there are 200,000 cubic feet of air passing per minute with 2 inches of water-gauge. The fan is worked by an engine having a 28-inch cylinder and $4\frac{1}{2}$-foot stroke, there being a piston rod of 4 inches' diameter on either side of the piston, the effective pressure of steam on the piston is 30 lbs., and it has a speed of 270 feet per minute resulting from 30 revolutions. The horse-power to work the engine without the fan has been ascertained to be 18.

The horse-power of the fan is $\frac{200{,}000 \times 5\cdot 2 \times 2}{33{,}000} = 63$. That of the engine is $28^2 \times \cdot 7854 = 615\cdot 753$ area of piston; $4^2 \times \cdot 7854 = 12\cdot 566$ area of piston-rod; $615\cdot 753 - 12\cdot 566 =$ say 603 effective area of piston $\frac{603 \times 30 \times 270}{33{,}000} = 148$ horse-power of fan engine. As it requires 18 horse-power to work the engine itself, $148 - 18 = 130$ as the useful horse-power of the engine. Therefore as $130 : 63 :: 100 : 48\cdot 5$ per cent., which is the useful effect of the fan.

As to the amount of air exhausted by fans of given dimensions, it is almost impossible to say what that might be; very much would depend upon the condition and size of the airways, and these vary, so that the same sized fan of the same make gives different results at different collieries, sometimes being assisted by the natural ventilation and sometimes not.

A centrifugal fan, properly proportioned, and employed merely in displacing air, that is, under no drag, should deliver (at a velocity equal to the tips of its blades) a stream of air having a sectional area equal to the breadth of its blades at their outer ends, multiplied by the circumference of the circle described by those ends.

Also, the greatest water-gauge which any centrifugal fan can afford is dependent upon the speed at which the tips of the blades can safely be driven. Theoretically the depression of water-gauge, due to the velocity of the periphery of a perfect fan is equal to twice the height of column necessary to create such velocity in a falling body.

Take the case of a fan 24 feet in diameter, and allow it to run 64 revolutions

per minute, it will be seen from the law $h = \frac{V^2}{64 \cdot 4}$ when V = the speed of the tips of vanes in feet per second, that theoretically the greatest water-gauge it could afford would be 2·954 inches, thus $h = \frac{(24 \times 3 \cdot 1416 \times \frac{64}{60})^2}{64 \cdot 4} = 100 \cdot 43$; twice this head = 200·86, and $\frac{200 \cdot 86}{68} = 2 \cdot 954$ inches of water-gauge, taking the atmospheric air at a temperature of 60° F. and at 30 inches barometric pressure.

Experiments seem to show that with a Guibal fan a certain amount of benefit is derived from the shutter and chimney, and that the water-gauge as actually taken during those experiments gave a slight excess over the theoretical water gauge.

Equivalent Orifice.—If an opening be cut in a thin plate and the latter be then placed at right-angles to the direction of air in motion so that the air in its passage is obstructed by the plate, it meets with resistance in passing through the opening. M. Murgue assimilates the workings of a mine to such an opening in calculations for ventilating purposes, which he calls the *equivalent orifice.*

To find the equivalent orifice for any given mine :—

Let Q = Quantity of air in cubic feet per second passing through the opening (*i.e.* circulating round the mine).
h_a = Ventilating pressure in feet of air column, required to overcome the resistance of the mine.
A = Opening in thin plate in square feet (*i.e. equivalent orifice*).
k = Co-efficient of contraction of orifice (*i.e. vena contracta* = ·65).

Then :—

$$Q = \sqrt{2\,gh_a} \times k\,A = \sqrt{2\,gh_a} \times \cdot 65\ A.$$

$$\therefore A = \frac{Q}{\cdot 65\ \sqrt{2\,gh_a}}$$

It is however often more convenient to use the following units, viz. :—

Q in thousands of cubic feet per minute.
h_a in inches of water-gauge.

When the formula becomes

$$A = \frac{0 \cdot 37\ Q}{\sqrt{h_a}} \quad \therefore Q = \frac{A\ \sqrt{h_a}}{0 \cdot 37} \text{ and } h_a = 0 \cdot 1369 \left(\frac{Q}{A}\right)^2.$$

The average value of A for English mines is said to be about 20 and for Belgian 8·6 square feet.

Orifice of Passage.—The air in being exhausted from a mine meets with obstruction at the ventilator, the effect of which is to reduce the duty of the ventilator. The observed depression produced by the ventilator is always higher than where ascertained in the roadways of approach, the increase being to some extent due to overcoming the various resistances in the ventilator. M. Murgue treats this as the *orifice of passage.*

As to the volume of the ventilative current required for any particular colliery, this will depend entirely upon its own circumstances. The volume of air inhaled by a man is 27·8 cubic feet per hour. Smyth, in his *Coal and Coal Mining*, says "In round numbers 100 cubic feet of air per minute may be required for the health and comfort of each person underground, or for 100 men, 10,000 cubic feet; but if fire-damp be given off at, say, the rate of 200 cubic feet per minute

we should need at the very least 30 times that amount of fresh air to dilute it, o 6,000 cubic feet in addition. Increase the number of men and liability to gas and 40,000 or 60,000 cubic feet of air may be indispensable for safety." In André's *Mining Engineering* there is a definite formula for finding the ventilative current necessary in a mine as follows:—

$$V = m\,24 + h\,72 + p\,192 + f\,(q \times 2{,}700 + s).$$

where V = Ventilative current in cubic feet a minute.
m = The number of persons employed.
h = The number of horses in the mine.
p = The weight in pounds of the gunpowder consumed an hour as a maximum.
f = A factor of safety which would vary in different districts as well as in different mines, so as to be 2, 3, 4, 5, or more times; this can only be determined by the judgment of the engineer, but it must not be taken at less than 2 under the most favourable circumstances of a mine worked by long-wall (post and stall requiring more) and yielding very little fire-damp.
q = The output or average quantity of coal raised a minute in tons.
and s = The exposed surface of the coal in square yards, which can be calculated from the output and the thickness of the seam.

A horse is assumed to breathe 6 times the quantity of air required by a man, and to require 3 times the quantity required by a man and his lamp.

Applying this rule to a mine worked by long-wall, in which say 400 tons per day of 8 hours are raised, 200 men employed underground and 10 horses, and 10 lbs. of gunpowder per hour are used, the extent of coal surface exposed being 600 square yards, we have $V = (200 \times 24) + (10 \times 72) + (10 \times 192) + 2\left(\frac{400}{8 \times 60} \times 2{,}700 + 600\right)$.

Then V = 13,140, that is taking f, the factor of safety at its lowest figure and assuming the mine to be fairly free of gas, but if it be fiery and the factor 5 be adopted, the quantity would be 21,690 cubic feet.

If Smyth's rule be applied to this example—

For the men	200 × 100 =	20,000
,, ,, horses	10 × 300 =	3,000
it gives		23,000 cubic feet, besides what

may be necessary for the gas, which is not definitely known.

CHAPTER XI.

ON THE FRICTION OF AIR IN MINES.

The Pressure necessary to Overcome Friction—Rate of Increase or Decrease—Power necessary to produce Ventilation—Rate of Increase or Decrease—Best Form of Airway—Examples on Pressures and Powers of Different Shaped Airways—Questions and Answers on Ventilation.

THE friction of air in mines arises from its rubbing along the top, bottom and sides of the aircourses in its course round the workings. It is not difficult to understand that the more rubbing surface there is presented to the air, the more friction there will be, and that the amount of rubbing surface depends upon the length and perimeter of the road along which the air is taken. It is also obvious that the faster the air is made to travel, the more will be the friction. The late Mr. Atkinson has most ably argued the theory of circulating the air in mines, and he says in his *Practical Treatise on the General Principles of Ventilation*,* that "the pressure required to overcome the friction of air increases and decreases in exactly the same proportion that the area or extent of the rubbing surface exposed to the air increases or decreases, so that when the velocity of the air and the sectional area of the airway, remain the same, the pressure required to overcome the friction is proportional to the area or extent of the rubbing surface exposed to it; and hence if we double or treble the extent of the rubbing surface, we also double or treble the friction, or what is the same, the force or pressure required to overcome it." Again he says "the pressure required to overcome the friction in the same airways varies in the same proportions that the *square* of the velocity of the air increases or decreases, so that a double velocity of air in the same airway meets with a *double double* or fourfold resistance, a treble velocity meets with a *treble treble* or ninefold resistance; and a velocity of four times as great gives rise to a resistance four times four or sixteen times as great. In the same way a half velocity meets with one half of a half or $\frac{1}{4}$th of the resistance; $\frac{1}{3}$rd of the velocity encounters only a third of a third or $\frac{1}{9}$th of the friction, and so on." . . . . . "It seems probable that for every foot of rubbing surface and for a velocity in the air of 1,000 feet per minute, the friction is equal to 0·26881 feet of air column of the same density as the flowing air, which is equal to a pressure, with air at 32,° of 0·0217 lb. per square foot of area of section. Calling this the *co-efficient of friction*, we have the following rules with respect to the friction of air in mines:—

Total pressure	$p\,a = k\,s\,v^2$
Rubbing surface	$s = \dfrac{pa}{kv^2}$
Velocity squared	$v^2 = \dfrac{pa}{ks}$
Co-efficient of friction	$k = \dfrac{pa}{sv^2}$
Pressure per foot	$p = \dfrac{ksv^2}{a}$
Area of section	$a = \dfrac{ksv^2}{p}$

* See pp. 34–55, 1st Edition, 1871.

where p = pressure per square foot.
a = square feet of sectional area.
s = the area of rubbing surface exposed to the air.
v = the velocity of the air in thousands of feet per minute, 1,000 feet per minute being taken as the unit of velocity.
k = the co-efficient of friction in the same terms or unit as p is taken in."

. . . . . . "The quantity of air only varies as the cube root of the *power*, and of the quantity of coals burnt to produce it; so that eight times the coals only double, and twenty-seven times the coals only treble the quantity of air circulating in a mine, whether the ventilation is produced by furnace action, ventilating machines, or otherwise, so long as the airways remain in the same unaltered state."

It may be learned from these quotations that theoretically airways should be as smooth and as free from obstructions as possible, because roughness and inequality such as would be caused by projecting pieces of rock or timber, or from falls in aircourses produce friction. Again, theoretically, the best form of aircourse is the circular, because a circle whose area is 1 square yard has a perimeter equal to 3·545 yards, whereas a square whose area is 1 square yard has a perimeter of 4 yards. The square form is preferable to the rectangular, for a rectangular airway 6 feet by $1\frac{1}{2}$ feet has an area of 1 square yard, but its perimeter is $2 + 2 + \frac{1}{2} + \frac{1}{2} = 5$ yards. It is not convenient to have circular airways in mines, so the square form should be adopted as far as practicable; also theoretically, large airways are preferable to a number of small ones representing the same area.

Example 1.—Supposing two airways lead from the downcast to the upcast shaft, having equal perimeters and areas, but one is, say, 800 yards long, and the other 400 yards long, the total air circulating being 12,428 cubic feet per minute, the quantity going into each airway will be inversely as the square root of the rubbing surface. As, however, the airways have equal perimeters, it is equally true that their quantities will be inversely as the square root of their lengths. Therefore to find the relative quantity that the 800-yard airway gets as compared with the 400-yard airway's quantity, proceed thus, as $\sqrt{800} : \sqrt{400}$, or as $\sqrt{2} : \sqrt{1}$, or as 1·4142 : 1;—that is, for every cubic foot going into the 800-yard airway, 1·4142 cubic feet will pass into the 400-yard airway. Knowing the total quantity circulating to be 12,428 cubic feet per minute, and the relative quantities to be 1 and 1·4142, the actual quantities will be found thus:—

For the 800-yard airway as 2·4142 : 1 : : 12,428 : 5,148 c. ft.
„ „ 400 „ „ as 2·4142 : 1·4142 : : 12,428 : 7,280 c. ft.

If, instead of these two airways, two of the same area and perimeter, but each 600 yards long between the two shafts could be substituted with the same pressure as before, there would not be quite so large a quantity of air as a total, for the quantity in a 600-yard road would be, as $\sqrt{600} : \sqrt{800}$: : 5,148 or as $\sqrt{3} : 2$: : 5,148 : 5,944 cubic feet for each 600-yard airway $= 5{,}944 \times 2 = 11{,}888$ cubic feet, for the two.

From this it is seen that the total quantity of air produced with a given ventilating pressure and rubbing surface would be less in two airways of equal length, than in two of unequal lengths, but as the power producing the ventilation is the quantity passing multiplied by the pressure, in the case of the two airways of equal length the power would be lessened in proportion to the reduced quantity. This can be more strikingly shown by imagining a case of more extreme modification. Take two airways, each of which is 400 feet long and passes 9,000 cubic feet per minute. With a constant pressure if one of them be shortened to 100

feet, its rubbing surface being $\frac{1}{4}$th of what is was, the volume of air then would be 9,000 × $\sqrt{4}$ = 18,000 cubic feet. If the length of the second be increased to 1,600 feet, its rubbing surface being 4 times what it previously was, then the volume of air would be 9,000 × $\sqrt{\frac{1}{4}}$ = 4,500 cubic feet. The total volume of air in the two airways therefore would be 18,000 + 4,500 = 22,500 cubic feet, or an increase of 25 per cent., although the rubbing surface is increased in the proportion of 17 to 8 or more than doubled, and the pressure has remained constant, though the power has been increased in accordance with the increased quantity.

That this is so, assume the airways to be 5 feet by 6 feet, giving a 30-foot area and 22 feet as the perimeter, and testing them by Atkinson's formula $p = \frac{ksv^2}{a}$ we have

for each of the equal airways $\frac{\cdot 26881 \times (400 \times 22) \times \cdot 09}{30} = 7\cdot 0966$ feet of air-column.

for the shortened airway $\frac{\cdot 26881 \times (100 \times 22) \times \cdot 36}{30} = 7\cdot 0966$ feet of air-column.

for the lengthened airway $\frac{\cdot 26881 \times (1{,}600 \times 22) \times \cdot 0225}{30} = 7\cdot 0966$ feet of air-column.

From this it is clear that though the *resistance* increases in proportion to the length of the airway, the quantity or volume of air varies inversely as the square root of the rubbing surface, other things being equal. For this reason, to compare the relative quantities that would flow through a square and a circular airway whose areas and lengths are equal, adopt the same proportion, thus if 10,000 cubic feet passed through a 6-foot square airway, and it were altered to a circular one of the same area and the pressure remained the same, the perimeter of the square airway would be 24, and the perimeter of a circle whose area = 36 is 21·27. Therefore, As $\sqrt{21\cdot 27} : \sqrt{24} :: 10{,}000 : 10{,}622$; that is, 10,622 cubic feet would pass through the circular airway. Again, if the square airway were altered to a circular one of the same area, and instead of the pressure remaining constant, the power had done so, in that case the quantity which would pass through the circular airway would be as $\sqrt[3]{21\cdot 27} : \sqrt[3]{24} :: 10{,}000 : 10{,}410$, as will be better understood when later on the power necessary to circulate the air is dealt with.

Example 2.—Supposing 20,000 cubic feet of air are produced in an airway 10 feet × 6 feet = 60 feet area, how much will be produced in an airway 5 feet × 6 feet = 30 feet area, the pressure being the same in each ?

The perimeter of the 60 feet area airway is 10 + 10 + 6 + 6 = 32 feet, and assuming 1,000 feet length of airway (it is immaterial what length is taken, so that it is the same in both airways) the rubbing surface in the 60 feet area airway is 32 × 1,000 = 32,000 square feet, and the velocity of the air is $\frac{20{,}000}{60} = 333\cdot\dot{3}$ which expressed in thousands of feet per minute = $\cdot\dot{3}$. By the formula $p = \frac{ksv^2}{a}$

$$\frac{\cdot 26881 \times 32{,}000 \times (\cdot\dot{3})^2}{60} = 15\cdot 9295 \text{ feet of air column.}$$

The 30-foot airway has a perimeter 6 + 6 + 5 + 5 = 22 and the rubbing surface on 1,000 feet length = 22,000.

To find the velocity in the 30-foot airway $v^2 = \frac{pa}{ks} \therefore v = \sqrt{\frac{pa}{ks}}$ and substi-

tuting the values of these letters $v = \sqrt{\frac{15{\cdot}9295 \times 30}{{\cdot}26881 \times 22{,}000}} = \sqrt{\frac{477{\cdot}885}{5{,}913{\cdot}82}} = \sqrt{{\cdot}0808082} = {\cdot}28427$ in thousands of feet $\therefore {\cdot}28427 \times 1{,}000 = 284{\cdot}27$ the velocity in feet per minute in the 30 feet area airway, and $284{\cdot}27 \times 30 = 8{,}528$ cubic feet per minute in the 30 feet area airway.

This result may be obtained in a simpler way. The one airway is just half the area of the other, and if the perimeters had borne the same ratio it is plain that ½ the quantity in the 60-foot airway would flow through the 30-foot airway, that is, 10,000 cubic feet would have passed through the 30-foot airway if its perimeter had been $\frac{32}{2} = 16$, but as its perimeter is 22, and as (other things being equal) the quantity varies inversely as the square root of the rubbing surface, the quantity could be found thus—As $\sqrt{22} : \sqrt{16} :: 10{,}000 : 8{,}528$ cubic feet as before.

Now, assume that the perimeters and rubbing surfaces are the same in the 60 feet area airway and the 30 feet area airway, then with the same pressure proceed to find what quantity would pass into the 30-foot airway, thus:—Whilst the relative areas of the two airways are in the same proportion as their rubbing surfaces, the quantities will also be proportionate to their areas, thus as 60 : 30 :: 20,000 : 10,000. But in that case the large airway's rubbing surface would be 2, and that of the smaller 1; if it is assumed to be the same, then (other things being equal) the quantity is inversely as the square root of the rubbing surface, and as $\sqrt{2} : \sqrt{1} :: 10{,}000 : 7{,}071$, which is the quantity in cubic feet per minute the smaller airway would get if 20,000 passed into the larger, and their perimeters and rubbing surfaces were the same.

The advantage of having large airways may be thus strikingly shown, for supposing one airway of 60 feet area, 10 feet by 6 feet, passing 20,000 cubic feet per minute as just given, and it were substituted for two airways each 5 feet by 6 feet, together representing the same area as the large one, the pressure remaining the same, the quantity of air through the two airways would be as $\sqrt{44} : \sqrt{32} :: 20{,}000 : 17{,}056$ cubic feet per minute; that is, the two airways would have 17,056 cubic feet per minute as compared with 20,000 cubic feet in the single airway of equal area.

Example 3.—If an airway 7 feet by 8 passes 63,480 cubic feet of air per minute to a point 320 yards from the downcast shaft, after which it is split into 4 airways as follow:—

1. 6 feet by 5 feet being 400 yards long
2. 6 feet by 6 feet ,, 300 ,, ,,
3. 6 feet by 4 feet ,, 280 ,, ,,
4. 5 feet by 4 feet ,, 240 ,, ,,

and it is required to know what current each of the four airways will pass, and what the water-gauge will be.

In considering this question it is plain the four airways get the 63,480 cubic feet amongst them; first proceed to find the relative volumes going into them, so as to afterwards ascertain their actual quantities. The relative and actual quantities are not affected by the length of the main aircourse leading to the point of split. That is, that given the 63,480 cubic feet at the point of split, the relative quantities passing into those splits will be the same whether the air has travelled some distance before reaching the point of split, or if on the other hand the splits lead from the bottom of the downcast shaft, so long as the total quantity is 63,480 cubic feet as stated. All the splits will be subject to the same pressure.

The relative quantities going into airways subject to the same pressure may be found by the formula $\sqrt{\frac{a^3}{s}}$, or $\sqrt{\frac{a}{\sqrt[3]{s}}} = R$, where $R =$ the relative volume

a = the sectional area of the airway, and s the rubbing surface of the airway. If the airways are of the same length then o the value of their perimeters may be substituted for s. Applying this formula to the splits in question,

For No. 1 airway $\sqrt{\frac{30^3}{26,400}} = 1{\cdot}0113$ as the relative volume

" " 2 " $\sqrt{\frac{36^3}{21,600}} = 1{\cdot}4697$ do. do.

" " 3 " $\sqrt{\frac{24^3}{16,800}} = {\cdot}907115$ do. do.

" " 4 " $\sqrt{\frac{20^3}{12,960}} = {\cdot}785674$ do. do.

Total 4·173789 of the do.

And the actual volumes will be found by proportion thus :—

for No. 1 airway As 4·173789 : 1·0113 :: 63,480 : 15,381·15 cubic ft.
" " 2 " As 4·173789 : 1·4697 :: 63,480 : 22,352·83 " "
" " 3 " As 4·173789 : ·907115 :: 63,480 : 13,796·53 " "
" " 4 " As 4·173789 : ·785674 :: 63,480 : 11,949·5 " "

Total 63,480·01 " "

The accuracy of this result may be checked by Atkinson's formula $p = \frac{ksv^2}{a}$ when the value of p should work out the same for each of the four airways.

For No. 1 airway $p = \frac{{\cdot}0217 \times 26,400 \times {\cdot}5127^2}{30} = 5{\cdot}0196$ lbs. per square foot.

" 2 " $p = \frac{{\cdot}0217 \times 21,600 \times {\cdot}6209^2}{36} = 5{\cdot}0196$ " "

" 3 " $p = \frac{{\cdot}0217 \times 16,800 \times {\cdot}57485^2}{24} = 5{\cdot}0196$ " "

" 4 " $p = \frac{{\cdot}0217 \times 12,960 \times {\cdot}59747^2}{20} = 5{\cdot}0196$ " "

showing that the same pressure satisfies all the splits.

But this pressure of 5·0196 lbs. is only part of the total, there is still to consider that required to pass the whole volume through the large airway. To find the value of p in this airway extending from the pit to the point of splitting $\frac{{\cdot}0217 \times 28,800 \times 1{\cdot}1336^2}{56} = 14{\cdot}34$ lbs. per square foot. Then $5{\cdot}0194 + 14{\cdot}34 = 19{\cdot}3594$ lbs. per square foot as the total pressure, and the water-gauge, according to the formula, would be $\frac{19{\cdot}3594}{5{\cdot}2} = 3{\cdot}72$ inches.

Another method of finding the quantities that would pass along the four splits is, by using Atkinson's formula, $v = \sqrt{\frac{pa}{ks}}$. Assume any value say 1 for p, and having found the relative values of v, the relative quantities in the airways will be these relative velocities multiplied by the areas of the different airways, from which the actual quantities may be obtained.

This method requires more figuring than the formula $R = \sqrt{\frac{a^3}{s}}$, but the student is recommended to try it and compare the result with what is here given.

Example 4.—A mine is ventilated by three splits of air A, B, C ;

A being 500 yards long, 5 feet by 6 feet; B is 800 yards long and 5 feet by 4 feet, and C is 700 yards long, 7 feet by 3 feet, all starting and rejoining at the same point. If the quantity in A is 35,000 cubic feet per minute, how much will B and C, which are subject to the same pressure as A, each take?

	Rubbing Surface.	Area
For A	33,000	30
B	43,200	20
C	42,000	21

By the formula $R = \sqrt{\frac{a^3}{s}}$ the relative quantities are

$$A = \sqrt{\frac{30^3}{33{,}000}} = \cdot 90453, \text{ the relative volume}$$

$$B = \sqrt{\frac{20^3}{43{,}200}} = \cdot 43033 \quad ,,$$

$$C = \sqrt{\frac{21^3}{42{,}000}} = \cdot 46957 \quad ,,$$

Total 1·80443

A's actual quantity is		35,000	cub. ft. per min.
∴ B's is	as ·90453 : ·43033 :: 35,000 :	16,651·2	do.
& C's is	as ·90453 : ·46957 :: 35,000 :	18,169·7	do.
	& the total quantity flowing is	69,820·9	do.

Example 5.—A mine is ventilated by 3 splits of air, A, B, C; A, taking 2,500 cubic feet per minute, B, 1,500 cubic feet per minute, and C, 2,000 cubic feet per minute, out of a total of 6,000 cubic feet, what will each split take if the total ventilation be increased to 75,000 cubic feet per minute?

The quantities would be in proportion thus—

A's quantity is	As 6,000 : 75,000 :: 2,500 :	31,250	cubic ft. per min.
B's ,,	,, 6,000 : 75,000 :: 1,500 :	18,750	do.
C's ,,	,, 6,000 : 75,000 :: 2,000 :	25,000	do.
	Total	75,000	do.

Example 6.—If the quantity passing round a mine in one current before splitting is 10,000 cubic feet per minute where the area of the aircourse is 20 feet (5 feet by 4 feet), and the rubbing surface is 24,000 square feet, what quantity will circulate when the current is split into 2, 3, 4, 5, 6, and 10 equal divisions, the pressure remaining the same?

The formula $R = \sqrt{\frac{a^3}{s}}$ to find relative quantities is equally applicable to this case. First of all take the case of one current of 10,000 cubic feet before splitting, to find the quantity that would pass into 2 equal divisions, the pressure remaining the same.

In the first case before splitting the area is 20 feet, and rubbing surface, 24,000 square feet.

In the second case, with 2 splits, there would be an area of 40 feet, and a rubbing surface, the same as before, 24,000. Therefore the relative quantities are

As $\sqrt{\frac{20^3}{24{,}000}} : \sqrt{\frac{40^3}{24{,}000}} :: 1$ or as $\sqrt{20^3} : \sqrt{40^3} :: 1 : 2{\cdot}8284$; therefore this simple rule is obtained, that if the rubbing surface and pressure remain unaltered the relative volumes obtained from splitting the air will be in the proportion of $\sqrt{a^3}$. Proceed now to find the relative quantities for 3, 4, 5, 6, and 10 equal divisions thus

For 3 splits as	$\sqrt{20^3} : \sqrt{60^3} :: 1 : 5{\cdot}19614$	as the relative volume.
" 4 "	$\sqrt{20^3} : \sqrt{80^3} :: 1 : 8{\cdot}$	do.
" 5 "	$\sqrt{20^3} : \sqrt{100^3} :: 1 : 11{\cdot}18033$	do.
" 6 "	$\sqrt{20^3} : \sqrt{120^3} :: 1 : 14{\cdot}6969$	do.
" 10 "	$\sqrt{20^3} : \sqrt{200^3} :: 1 : 31{\cdot}622774$	do.

If 10,000 cubic feet be the volume before splitting then

						cub. ft. along
For 2 splits as	1 : 2·8284	:: 10,000 :	28,284,	or 14,142		each split.
" 3 "	1 : 5·19614	:: 10,000 :	51,961·4,	or 17,320·5		do.
" 4 "	1 : 8·	:: 10,000 :	80,000	or 20,000		do.
" 5 "	1 : 11·18033	:: 10,000 :	111,803·3,	or 22,360·6		do.
" 6 "	1 : 14·6969	:: 10,000 :	146,969	or 24,495		do.
" 10 "	1 : 31·622774	:: 10,000 :	316,227·74	or 31,622·774		do.

The same result may be arrived at by working out Atkinson's formula.

Example 7.—Supposing in a mine 50,000 cubic feet of air at the shaft have to be split into 5 distinct currents of equal volume and subject to the same pressure, that is 10,000 cubic feet are to pass along each of 5 roads of different lengths, No. 1 being 200 yards, No. 2, 400 yards, No. 3, 600 yards, No. 4, 800 yards, and No. 5, 1,000 yards long, all having the same sectional areas and perimeters.

It is evident that all must have regulators fixed in them except the longest. Supposing 9 feet (or any other figure may be assumed) to represent the sectional area of the regulator in No. 1 airway, which it is obvious must be the least in area, proceed to find the relative areas of the others.

Using the formula $R = \sqrt{\frac{a^3}{s}}$ and letting 2 represent the value of s, then the relative volume for No. 1 airway is $\sqrt{\frac{9^3}{2}} = 19{\cdot}092$ and since equal volumes are to go into each airway, it is evident that 19·092 must be the relative volume for each of the other airways. Now take No. 2, the rubbing surface of which is 4 and the area of the regulator a will be found thus $\sqrt{\frac{a^3}{4}} = 19{\cdot}092 \therefore \sqrt{a^3} = 2 \times 19{\cdot}092$ and $a^3 = 1{,}458 \therefore a = 11{\cdot}3396$, which is the area No. 2 regulator should be if No. 1 is 9 feet. Similarly for No. 3 $\sqrt{\frac{a^3}{6}} = 19{\cdot}092 \therefore \sqrt{a^3} = \sqrt{6} \times 19{\cdot}092$ and $\sqrt{a^3} = 46{\cdot}765$; $a^3 = 2{,}187$ and $a = 12{\cdot}98$, which is the area No. 3 regulator must be if No. 1 is 9 feet. Similarly for No. 4 airway $\sqrt{\frac{a^3}{8}} = 19{\cdot}092 \therefore \sqrt{a^3} = \sqrt{8} \times 19{\cdot}092$ and $\sqrt{a^3} = 54 \therefore a^3 = 2{,}916$ and $a = 14{\cdot}2866$, which is the area of No. 4 airway regulator if No. 1 is 9 feet. Taking the last, or No. 5 airway, $\sqrt{\frac{a^3}{10}} = 19{\cdot}092 \therefore \sqrt{a^3} = \sqrt{10} \times 19{\cdot}092$ and $\sqrt{a^3} = 60{\cdot}374 \therefore a^3 = 3{,}645$ and $a = 15{\cdot}39$, which is the area of No. 5 regulator if No. 1 is 9 feet.

If now a represent in feet the area of the regulator in No. 1 airway, $a_{,}$, that of No. 2, $a_{,,}$, that of No. 3, $a_{,,,}$, that of No. 4, and $a_{,,,,}$, that of No. 5, then it is plain that

$$\sqrt{\frac{a^3}{2}} = \sqrt{\frac{a^3_{\prime}}{4}} = \sqrt{\frac{a^3_{\prime\prime}}{6}} = \sqrt{\frac{a^3_{\prime\prime\prime}}{8}} = \sqrt{\frac{a^3_{\prime\prime\prime\prime}}{10}} = 19{\cdot}092$$

$$\therefore \frac{a^3}{2} = \frac{a^3_{\prime}}{4} = \frac{a^3_{\prime\prime}}{6} = \frac{a^3_{\prime\prime\prime}}{8} = \frac{a^3_{\prime\prime\prime\prime}}{10} = 364{\cdot}5$$

and $$\frac{a}{\sqrt[3]{2}} = \frac{a_{\prime}}{\sqrt[3]{4}} = \frac{a_{\prime\prime}}{\sqrt[3]{6}} = \frac{a_{\prime\prime\prime}}{\sqrt[3]{8}} = \frac{a_{\prime\prime\prime\prime}}{\sqrt[3]{10}} = 364{\cdot}5$$

$$\begin{aligned} a &= 364{\cdot}5 \times \sqrt[3]{2} \\ a_{\prime} &= 364{\cdot}5 \times \sqrt[3]{4} \\ a_{\prime\prime} &= 364{\cdot}5 \times \sqrt[3]{6} \\ a_{\prime\prime\prime} &= 364{\cdot}5 \times \sqrt[3]{8} \\ a_{\prime\prime\prime\prime} &= 364{\cdot}5 \times \sqrt[3]{10} \end{aligned}$$

But as the factor 364·5 is common to them all, the relative value of a, $a_{\prime}$, &c., will not be affected if it be omitted, then this simple rule to find the areas of regulators to be placed in roads of the same sectional areas and perimeters and subject to the same pressure, but of different lengths, is obtained—that the areas will be according to the cube root of the rubbing surfaces, or, what is the same thing (the perimeters being equal), to the lengths.

Thus for No. 1, $\sqrt[3]{200} = 5{\cdot}848$ as the relative area.
" " 2, $\sqrt[3]{400} = 7{\cdot}368$ do.
" " 3, $\sqrt[3]{600} = 8{\cdot}434$ do.
" " 4, $\sqrt[3]{800} = 9{\cdot}283$ do.
" " 5, $\sqrt[3]{1{,}000} = 10{\cdot}$ do.

If, as stated, No. 1 regulator has to be 9 feet area, the areas of the others may be found by proportion, thus :—

As 5·848 : 9 :: 7·368 : 11·3396 area for No. 2,
5·848 : 9 :: 8·434 : 12·98 " " " 3,
5·848 : 9 :: 9·283 : 14·2866 " " " 4,
5·848 : 9 :: 10· : 15·39 " " " 5,

which is the same result as given before. The effect of placing regulators is, of course, to lessen the total quantity of air circulating, but there may be reasons why it is desirable, and even necessary.

Example 8.—Supposing 9,000 cubic feet per minute circulate through a regulator 30 inches × 20, and it is desired to find how much will circulate if made 30 inches by 30.

The areas would be 30 × 20 = 600 square inches, and 30 × 30 = 900 square inches, and the pressure and rubbing surface are the same in both cases. Therefore by the formula $R = \sqrt{\frac{a^3}{s}}$, the relative quantity is as $\sqrt{600^3}$: $\sqrt{900^3}$ :: 9,000 : 16,534 ; therefore, 16,534 cubic feet per minute would pass with the regulator altered to 30 inches by 30, other things remaining the same.

Example 9.—If 100,000 cubic feet of air pass per minute with a 2-inch water-gauge, and it is required to know the units of work producing the ventilation, 100,000 × 5·2 × 2 = 1,040,000 units of work.

Example 10.—If it is desired to know the units of work required to overcome the friction in a circular air-course 6 feet in diameter and 500 yards long, with 4,807 cubic feet passing per minute, $p = \frac{ksv^2}{a} = \frac{{\cdot}0000000217 \times 28{,}274{\cdot}4 \times 170{\cdot}013^2}{28{\cdot}2744} =$ ·6272. Therefore, 4,807 × ·6272 = 3,015 units of work.

Example 11.—If 20,000 cubic feet of air pass, the water-gauge being ·9 inch, and it is wanted to know what quantity will pass when the water-gauge is 2·6 inches, remember that the quantity varies as the square root of the pressures. Therefore, As $\sqrt{\cdot 9} : \sqrt{2\cdot 6} :: 20{,}000 : 33{,}993$ cubic feet.

Example 12.—If it is desired to double the quantity of the air, the ventilating pressure must be increased $2^2 = 4$ times.

Example 13.—If with a water-gauge of ·1 inch 20,000 cubic feet of air per minute are obtained, and afterwards the quantity is increased to 60,000 cubic feet per minute, and it is desired to know the height of the water-gauge, remember that the square of the quantity of the air is proportional to the water-gauge, and as there are 3 times the quantity passing, the gauge will be $3^2 = 9$ times higher, and $9 \times \cdot 1 = \cdot 9$ inch as the height of water-gauge.

Example 14.—Supposing two airways (subject to the same pressure) of the same area, passing a total quantity of 100,000 cubic feet of air per minute, the resistances in the airways being in the proportion of 5 to 1, and it is desired to know the quantity going along each.

By the formula $R = \sqrt{\frac{a^3}{s}}$ for the one airway $R = \sqrt{\frac{a^3}{s}} = 1$, supposing a is 1 and s also 1; then for the second airway $a = 1$ and $s = 5$ $\therefore R = \sqrt{\frac{1^3}{5}} = \cdot 447214$. The sum of the two relative quantities is $1 + \cdot 447214 = 1\cdot 447214$, and the actual quantities going along each airway the total of which is 100,000, will be found by proportion, thus:—

As 1·447214 : ·447214	:: 100,000 :	30,901	cubic	feet;
and as 1·447214 : 1·	:: 100,000 :	69,098	,,	,,
	Total	99,999	,,	,,

per minute, practically 100,000, the difference being due to error in neglecting decimals.

Example 15.—The junction of the two intakes at a colliery having 3 shafts (2 downcast and one upcast), is 300 yards from the downcast in one case, and 600 yards in the other, and the distance from the junction to the upcast is 200 yards. The area of all the airways is the same, being 6 feet by 6, and all are subject to the same pressure. What total quantity of air will pass, and what quantity in each airway, the water-gauge at the bottom of the upcast being 1·5 inch.

Assume that $v =$ the velocity of the air per minute through the longer intake,
and $v_{,} =$ the velocity do. do. do. the shorter do.

$$\text{then } p = \frac{\cdot 0000000217 \times 600 \times 3 \times 24 \times v^2}{36} \quad (1)$$

$$\text{and also } p = \frac{\cdot 0000000217 \times 300 \times 3 \times 24 \times v_{,}^2}{36} \quad (2)$$

Therefore the right hand side of (1) = the right hand side of (2), and by cancelling common factors $2v^2 = v_{,}^2$, $\therefore 1\cdot 414213v = v_{,}$. As the areas of the airways are equal, the velocity of the air in that part between the junction and the upcast will be equal to the sum of the velocities in the two intakes, that is, it will be $v + 1\cdot 414213v = 2\cdot 414213v$. As the water-gauge at the bottom of the upcast shaft is 1·5 inch, then $5\cdot 2 \times 1\cdot 5 = 7\cdot 8$ lbs. per square foot as the total pressure producing ventilation. If p represents that part of the pressure which

is expended in overcoming the resistance met with by the air in passing through that part of the mine between the junction and the upcast;

Then $p = \dfrac{\cdot0000000217 \times 200 \times 3 \times 24 \times (2\cdot414213v)^2}{36}$.

The pressure for each of the intakes from the downcast to the point of junction will be $7\cdot8 - p$. Applying this to the longest intake, thus:—

$$7\cdot8 - p = \frac{\cdot0000000217 \times 600 \times 3 \times 24 \times v^2}{36}$$

and therefore $$\frac{p}{7\cdot8 - p} = \frac{\dfrac{\cdot0000000217 \times 200 \times 3 \times 24 \times (2\cdot414213\,v)^2}{36}}{\dfrac{\cdot0000000217 \times 600 \times 3 \times 24 \times v^2}{36}}$$

Cancel the common factors thus:—

$$\frac{p}{7\cdot8 - p} = \frac{2\cdot414213^2}{3} = 1\cdot9428$$

$$p = 15\cdot15387 - 1\cdot9428\,p$$

$$2\cdot9428\,p = 15\cdot15387.$$

$p = 5\cdot1495$, and the pressure in each of the two intakes is $7\cdot8 - 5\cdot1495 = 2\cdot6505$.

To find the velocity of air between the junction and the upcast, $v = \sqrt{\dfrac{5\cdot1495 \times 36}{\cdot0000000217 \times 200 \times 3 \times 24}} = 770\cdot23$ as the velocity in feet per minute, and therefore the total volume passing is $770\cdot23 \times 36 = 27{,}728\cdot28$ cubic feet.

To find the velocity in the longer intake, $v = \sqrt{\dfrac{2\cdot6505 \times 36}{\cdot0000000217 \times 600 \times 3 \times 24}} = 319\cdot04$, and therefore the volume passing through the longer intake is $319\cdot04 \times 36 = 11,\ 485\cdot44$ cubic feet.

Similarly for the shorter airway, $v = \sqrt{\dfrac{2\cdot6505 \times 36}{\cdot0000000217 \times 300 \times 3 \times 24}} = 451\cdot2$, and therefore the volume passing through the shorter intake is $451\cdot2 \times 36 = 16{,}243\cdot2$ cubic feet. The accuracy of these quantities is shown by adding together the intake volumes to the point of junction, and observing that they agree with the total thus, $11{,}485\cdot44 + 16{,}243\cdot2 = 27{,}728\cdot64$; and further by multiplying the quantity $11{,}485\cdot44$ in the long airway by $1\cdot414213$, when, as a result, 16,243 cubic feet per minute is obtained as the volume for the shorter intake airway.

Example 16.—An aircourse is 8,000 feet long, 5 feet by 5 feet, and the quantity of air circulating is 6,250 cubic feet per minute in a district where 90 miners work; it is desired to convey 250 cubic feet per minute to each miner, and in order to do so, state what size the aircourse must be made, the ventilating pressure remaining the same.

Here there are 6,250 cubic feet per minute in an airway 8,000 feet long, its section being 5 feet by 5, and it is necessary to enlarge the area of the same length of airway to pass $250 \times 90 = 22{,}500$ cubic feet per minute with the same pressure.

In this case the relative quantities passing in two airways are given, the dimensions of one being stated, and the other has to be ascertained. By the formula $R = \sqrt{\dfrac{a^3}{s}}$, and using the value of o instead of s the relative volume going into the 5-foot airway is $\sqrt{\dfrac{25^3}{20}} = 27\cdot95$, and therefore if $a =$ the

area of the required airway, and o its perimeter then $\sqrt{\frac{a^3}{o}} = 27\cdot95 \times \frac{22,500}{6,250} = 27\cdot95 \times 3\cdot6 = 100\cdot62$ as the relative volume for the altered airway.

The difficulty now is that the value of o is not known, but assume the airway to be square, then the value of o will be $4\sqrt{a}$ or $\sqrt{16a}$. Therefore $\sqrt{\frac{a^3}{\sqrt{16a}}} = R$, where R represents the relative quantity.

$\therefore \frac{a^3}{\sqrt{16a}} = R^2$; $a^3 = R^2 \times \sqrt{16a}$ and $a^3 = \sqrt{16aR^4}$; $a^6 = 16aR^4$; $a^5 = 16 R^4$, and therefore $a = \sqrt[5]{16R^4}$.

Substituting the value of R, which in this case for the altered airway was found to be 100·62, then $a = \sqrt[5]{16 \times 100\cdot62^4}$, and therefore (by using logarithms) $a = 69\cdot659$. $\sqrt{69\cdot659} = 8\cdot346$, or 8 feet 4·152 inches by 8 feet 4·152 inches as the size of the square airway necessary.

The result shows that it would be much easier to split the air than to attempt to carry it in one aircourse of the unusual size of 8 feet 4 inches square.

If instead of a square airway it had been desirable in the above example to have a circular one, then if a represented its area, its perimeter would be $3\cdot545\sqrt{a}$. In that case to find the area required proceed thus $\sqrt{\frac{a^3}{3\cdot545\sqrt{a}}} = R$; $\frac{a^3}{\sqrt{12\cdot567a}} = R^2$; $a^3 = R^2 \times \sqrt{12\cdot567a}$; $a^3 = \sqrt{12\cdot567aR^4}$; $a^6 = 12\cdot567aR^4$; $a^5 = 12\cdot567R^4$; $a = \sqrt[5]{12\cdot567R^4}$; and substituting the value of R as before, $a = \sqrt[5]{12\cdot567 \times 100\cdot62^4}$, and therefore $a = 66\cdot375$, and the diameter of the airway would be $\sqrt{\frac{66\cdot375}{\cdot7854}} = 9\cdot193$ feet.

Again, if it had been desirable to have a rectangular road instead of a square or circular one, either the height or the width should be stated, probably the height of the seam would be known and given.

In the example being considered, if the height of the seam is 6 feet, proceed to find the width and area of the rectangular road thus :—

If x = its width in feet. Then $6x$ = its area and $12 + 2x$ = its perimeter. Then $\sqrt{\frac{(6x)^3}{12+2x}} = R$; and $\frac{(6x)^3}{12+2x} = R^2$; $(6x)^3 = 12R^2 + 2R^2x$.

$\therefore x^3 = \frac{12R^2 + 2R^2x}{216}$ and substituting the known value of R

$x^3 = \frac{12(100\cdot62)^2 + 2(100\cdot62^2)x}{216}$; $x^3 = \frac{121,500 + 20,250x}{216} = 93\cdot75x + 562\cdot5$; $x^3 - 93\cdot75x - 562\cdot5 = 0$.

Here is a cubic equation, and therefore proceed to find the value of x by the following trigonometrical formula.

$$x^3 - px - Q = 0$$

$$\sin. a = \frac{p}{3Q} 2\sqrt{\frac{p}{3}}$$

$$\tan. B = \sqrt[3]{\tan. \tfrac{1}{2}a}.$$

$$x = \frac{2\sqrt{\frac{p}{3}}}{\sin. 2B.}$$

Substituting the values of p and Q in the formula

$$\sin.\ a = \frac{93{\cdot}75}{1{,}687{\cdot}5} \times 2 \times \sqrt{\frac{93{\cdot}75}{3}}$$

$$a = 38^\circ 24'$$

$$\text{and } \tfrac{1}{2}\, a = 19^\circ 12'$$

$$\tan.\ B = \sqrt[3]{\text{Tan. } 19^\circ 12'}$$

$$\text{Log. tan. } 19^\circ 12' = 9{\cdot}541875$$

Less 10

which divided by 3 to cube root $)\bar{1}{\cdot}541875$

$\bar{1}{\cdot}847292$

add 10

$9{\cdot}847292$

$= \text{Log. tan. of } 35^\circ 8'$

$$2\ B = 70^\circ 16'$$

$$x = \frac{2\sqrt{\frac{93{\cdot}75}{3}}}{\sin.\ 70^\circ 16'}$$

$$x = 11{\cdot}88$$

11·88 feet then is the width of the rectangular airway, and $6 \times 11{\cdot}88 = 71{\cdot}28$ square feet of sectional as compared with 69·659, the area of the square airway and 66·375 the area of the circular airway.

If the water-gauge in the above instance is required, then $p = \frac{{\cdot}0217 \times 160{,}000 \times {\cdot}25^2}{25}$ $= 8{\cdot}68$ lbs. per square foot pressure and $\frac{8{\cdot}68}{5{\cdot}2} = 1{\cdot}67$ inch as the water-gauge.

Observing now somewhat closely the examples just worked out, it is seen that to increase the quantity from 6,250 cubic feet per minute to 22,500 cubic feet per minute the airway must be increased from 5 feet square to one of 8·346 feet square, the pressure and length of airway remaining constant.

It may now be shown that the simplest way of finding the desired side of square for the altered airway is by taking the $\frac{2}{5}$th root of the ratio of the quantities of air and multiplying this result by the side of the known airway, thus in the present example $\left(\frac{22{,}500}{6{,}250}\right)^{\frac{2}{5}} \times 5 = 1{\cdot}66925 \times 5 = 8{\cdot}34625$ feet as the side of the square forming the altered airway, being the same result as already proved.

For circular airways this rule holds good also, applied to the diameters of the airways in the same way as applied to the side of a square airway. That this is true may be seen by another example.

Example 17.—If 8,000 cubic feet of air pass through a circular airway whose diameter is 5 feet, the length being 10,000 feet, and the quantity has to be increased to 20,000 cubic feet per minute by enlarging the airway in circular form, the pressure remaining the same, proceed thus :—

The ratio of the altered quantity to the old quantity would be $\frac{20{,}000}{8{,}000} = 2{\cdot}5$

and $\left(2{\cdot}5\right)^{\frac{2}{5}} = 1{\cdot}4427$; $1{\cdot}4427 \times 5 = 7{\cdot}2135$, which is the diameter in feet that the altered airway should be. That this is so, can be shown by proving the value of p in each case, and it will be found to agree, thus :—

Before enlarging $p = \dfrac{{\cdot}0000000217 \times 157{,}080 \times 407{\cdot}43^2}{19{\cdot}635} = 28{\cdot}81$ lbs. per sq. ft.

After enlarging $p = \dfrac{{\cdot}0000000217 \times 7{\cdot}2135 \times 3{\cdot}14159 \times 10{,}000 \times \left(\dfrac{20{,}000}{7{\cdot}2135^2 \times {\cdot}7854}\right)^2}{7{\cdot}2135^2 \times {\cdot}7854}$

$= 28{\cdot}81$ lbs.

Referring to *Example* 16, the rule there given also holds good for rectangular airways applied to the height and to the width of the airways, that is, the $\frac{2}{5}$th root of the ratio of increased or decreased quantity must be multiplied by the height of the original airway to give the height of the altered airway, and by the width of the original airway to give the width of the altered airway.

That this is true, also may be proved by means of the following example.

Example 18.—An airway 5,000 feet long, 5 feet high, and 7 feet wide, passes 10,000 cubic feet of air per minute, and it is desired to enlarge the airway in the same rectangular form to pass 30,000 cubic feet of air per minute, the pressure remaining the same.

Here the ratio of increased quantity to the original would be $\dfrac{30{,}000}{10{,}000} = 3$ and $\left(3\right)^{\frac{2}{5}} = 1{\cdot}55184$. The height of the altered airway, therefore, must be $1{\cdot}55184 \times 5 = 7{\cdot}7592$ feet, and the width $1{\cdot}55184 \times 7 = 10{\cdot}86288$, so that the altered airway must be $10{\cdot}86288$ feet wide and $7{\cdot}7592$ feet high. Again prove the accuracy of this by testing the value of p in each case, thus :—

Before enlarging $p = \dfrac{{\cdot}0000000217 \times 120{,}000 \times 285{\cdot}7^2}{35} = 6{\cdot}073$ lbs. per sq. ft.

After enlarging $p = \dfrac{{\cdot}0000000217 \times 186{,}220{\cdot}8 \times 355{\cdot}925^2}{84{\cdot}287} = 6{\cdot}073$ do.

Example 19.—Suppose an airway as in the last example 5,000 feet long, 5 feet high, and 7 feet wide, passing 10,000 cubic feet per minute, and it is desired to enlarge the airway in a circular form to pass 30,000 cubic feet of air per minute, the pressure remaining the same.

Using the value of o for the 5 feet by 7 feet airway $R = \sqrt{\dfrac{35^3}{24}} = 42{\cdot}2665$, and if a = the area of the required airway and o its perimeter, then $\sqrt{\dfrac{a^3}{o}} = 42{\cdot}2665 \times \dfrac{30{,}000}{10{,}000} = 42{\cdot}2665 \times 3 = 126{\cdot}7995$ as the relative volume for the altered airway. Therefore, as in *Example* 16, $a = \sqrt[5]{12{\cdot}567\ R^4}$ and substituting the value of R for the altered airway $a = \sqrt[5]{12{\cdot}567 \times 126{\cdot}7995^4} = 79{\cdot}862$ feet; its diameter therefore is $\sqrt{\dfrac{79{\cdot}862}{{\cdot}7854}} = 10{\cdot}0838$ feet, and its perimeter $10{\cdot}0838 \times 3{\cdot}14159 = 31{\cdot}679$ feet. If the value of p be now worked out for this airway according to the formula $p = \dfrac{ksv^2}{a}$, it will be found as in the last example for a rectangular road to be $6{\cdot}073$ lbs. per square foot.

Example 20.—Supposing a 5-foot square airway with the conditions given in *Example* 16, of 6,250 cubic feet of air passing along it, and this quantity is to be increased to 22,500 cubic feet per minute with the same pressure along the same length of road, but finding it not practicable to use a road of 8·34625 feet square, it is decided to make an additional road or roads of the height of the seam, viz., 5 feet.

The old airway would continue passing its quantity of 6,250 cubic feet per minute, so that the additional road or roads must pass 22,500 — 6,250 = 16,250 cubic feet per minute.

Here it is evident that it would be better to use two additional roads to provide for the 16,250 cubic feet as the height is stated to be 5 feet. Adopting this plan of passing $\left(\frac{16,250}{2}\right) = 8,125$ cubic feet per minute along each of the extra roads, proceed to find the value of a side forming a square airway to pass 8,125 cubic feet thus; $\left(\frac{8,125}{6,250}\right)^{\frac{2}{5}} = 1·11065$ as the side of square if that of the original airway is 1, and therefore $1·11065 \times 5 = 5·55325$ as the side of the square to pass 8,125 cubic feet, and its area would be 30·8385, and perimeter 22·213.

If, however, the height is to be restricted to 5 feet, the 5·55325-foot square airways will not be available, and, in that case, proceed as in *Example* 16 to find the size of a rectangular airway. There the value of R for the 5-foot airway is 27·95. Then if x = the width in feet of the rectangular road to pass 8,125 cubic feet per minute when subject to the same pressure as the 5 feet square airway; $5x$ = its area and $10 + 2x$ = its perimeter. Therefore $\sqrt{\frac{(5x)^3}{10 + 2x}} = R$ and $x^3 = \frac{10\ R^2 + 2\ R^2 x}{125}$. The value of R for the rectangular road is $27·95 \times \frac{8,125}{6,250} = 36·335$, and substituting it in the above; $x^3 = \frac{10\,(36·335)^2 + 2\,(36·335^2)x}{125}$, $\therefore x^3 = \frac{13,203 + 2,640·6x}{125}$. $x^3 = 21·125x + 105·624$, $\therefore\ x^3 - 21·125x - 105·624 = 0$.

Proceed to find the value of x in this cubic equation by the trigonometrical formula given in *Example* 16.

$$\text{Thus sin. } a = \frac{21·125}{316·872} \times 2 \times \sqrt{\frac{21·125}{3}}$$

$$a = 20° \ 44'$$

$$\tfrac{1}{2} a = 10° \ 22'$$

$$\text{tan. B} = \sqrt[3]{\text{tan. } 10° \ 22'}$$

$$\begin{array}{rr}
\text{Log. tan. } 10° \ 22' = & 9·262292 \\
\text{Less} & 10 \\
\hline
\text{Divide by 3 to cube root} & 3\,)\ \bar{1}·262292 \\
\hline
 & \bar{1}·754097 \\
\text{Add} & 10 \\
\hline
 & 9·754097
\end{array}$$

$$= \text{Log. tan. of } 29° \ 34'$$

$$2\ \text{B} = 29° \ 34' \times 2 = 59° \ 8'$$

$$x = \frac{2\sqrt{\frac{21·125}{3}}}{\text{sin. } 59° \ 8'}$$

= 6·182, which is the width of the road required in feet.

So that the quantity may be increased as desired by substituting a square road 8·34625 high for the original road as shown in *Example* 16, or by the use of two additional roads as well as the old one, each of which may be either 5·55325 feet square or 5 feet high by 6·182 feet wide.

Example 21.—Referring to *Example* 3 in which is given and worked out a question of an airway 7 feet by 8 passing 63,480 cubic feet of air per minute, to a point from which it is split into 4 airways, No. 1 being 6 feet by 5 feet and 400 yards long; No. 2, 6 feet square 300 yards long; No. 3, 6 feet by 4 feet, 280 yards long; No. 4, 5 feet by 4 feet 240 yards long, and in which the quantities were shown to be as follow: No. 1, 15,381·15 cubic feet; No. 2, 22,352·83 cubic feet; No. 3, 13,796·53 cubic feet; No. 4, 11,949·5 cubic feet; now if it be desirable to ascertain the sectional area necessary to pass an equal quantity along each, proceed to find the size as follows.

A total quantity of 63,480 cubic feet divided amongst 4, means $\frac{63{,}480}{4} =$ 15,870 cubic feet along each. Dealing with No. 1, it is desired to substitute a road for one 6 feet by 5 which now passes 15,381·15 cubic feet. Therefore $\left(\frac{15{,}870}{15{,}381 \cdot 15}\right)^{\frac{2}{5}} = 1 \cdot 0126$ as the ratio of the height and width to those of the original airway, if the height and width of the latter is represented by 1. Therefore, $1 \cdot 0126 \times 6 = 6 \cdot 0756$ and $1 \cdot 0126 \times 5 = 5 \cdot 063$. Therefore, for the same length of No. 1 airway as before it must be 6·0756 feet by 5·054.

Dealing next with No. 2, the quantity of which must be decreased from 22,352·83 to 15,870. Here $\left(\frac{15{,}870}{22{,}352 \cdot 83}\right)^{\frac{2}{5}} = \cdot 87196$ and $\cdot 87196 \times 6 = 5 \cdot 23176$ as the side of the square airway for No. 2. For No. 3, $\left(\frac{15{,}870}{13{,}796 \cdot 53}\right)^{\frac{2}{5}} =$ 1·0576 and 1·0576 multiplied by 6 and 4 respectively give 6·3465 and 4·2304, the dimensions in feet of the altered No. 3 roadway. For No. 4, $\left(\frac{15{,}870}{11{,}949 \cdot 5}\right)^{\frac{2}{5}} = 1 \cdot 1202$ and this number multiplied by 5 and 4 gives 5·601 and 4·4808 respectively as the dimensions in feet of No. 4 altered airway.

If tested the value of p according to Atkinson's formula will be found equal to 5·0196 lbs. per square foot in each case of altered road, the same as given before in *Example* 3 for the original roadways. Or, if tested by the formula $R = \sqrt{\frac{a^3}{s}}$ or $\sqrt{\frac{a}{\sqrt[3]{s}}}$, or since in cases where R must be the same in each on account of roads passing equal quantities the result will not be affected if the sign of the square root be removed and then,

$$\text{For No. 1} \quad R = \frac{30 \cdot 71}{\sqrt[3]{26{,}685 \cdot 12}} = 1 \cdot 028$$

$$\text{,,} \quad 2 \quad R = \frac{27 \cdot 37}{\sqrt[3]{18{,}834 \cdot 336}} = 1 \cdot 028$$

$$\text{,,} \quad 3 \quad R = \frac{26 \cdot 844}{\sqrt[3]{17{,}767 \cdot 68}} = 1 \cdot 028$$

$$\text{,,} \quad 4 \quad R \quad \frac{25 \cdot 097}{\sqrt[3]{14{,}517 \cdot 792}} = 1 \cdot 028$$

Example 22.—If two square airways each 14 feet area and therefore necessarily having the same perimeters, but one of them is 800 and the other 400 yards long, both subject to the same pressure; and if the total quantity in both

airways is 10,000 cubic feet per minute and it is desired to know the quantity passing in each, and also what the area of the short airway should be so that each may pass an equal quantity proceed first as in *Example* 1. The relative quantities passing into the two airways is as $\sqrt{2} : \sqrt{1}$ or as 1·4142 : 1. The sum of these relative quantities is 2·4142, and therefore the actual quantities passing are

For the 800-yard airway as 2·4142 : 1 : : 10,000 : 4,142 cub. ft.

„ 400 do. 2·4142 : 1·4142 : : 10,000 : 5,858 cub. ft.

Next, if each airway is to have an equal quantity passing through it with the same pressure, proceed by the formula $R = \sqrt{\frac{a^3}{s}}$, but as the quantities in the two airways are to be equal, the result is not affected if the square root sign be omitted. For the 14 feet area airway, which is 400 yards long $R = \frac{14^3}{17{,}960} = \cdot1527845$. If $a =$ the area of the square airway 800 yards or 2,400 feet long, which, being subject to the same pressure as the 14 feet area one, is to pass a similar quantity of 5,858 cubic feet per minute, then its perimeter is represented by $4\sqrt{a}$ or $\sqrt{16a}$. The value of R therefore for the proposed airway is $\frac{a^3}{2{,}400\sqrt{16a}} = \cdot1527845$ and $a^3 = 366\cdot68 \times \sqrt{16a}$; $a^3 = \sqrt{2{,}151{,}300\,a}$; $a^6 = 2{,}151{,}300a$; $a^5 = 2{,}151{,}300$ and $a = 18\cdot473$ which is the area the longer airway must be made if the shorter one is to remain 14 feet area and subject to the same pressure, or, if the long one is to remain 14 feet, then the shorter one would be

As 18·473 : 14 : : 14 : 10·61 feet area.

A square airway 10·61 feet area 400 yards long, and a square airway 14 feet area 800 yards long, both subjected to the same pressure, would always pass equal quantities of air, whether the pressure was increased or decreased, as would also a square airway 14 feet area 400 yards long and a square airway 18·473 feet area 800 yards long under the same circumstances.

If the pressure per square foot was maintained, the quantity passing in each airway would be 4,142 cubic feet per minute or a total of 8,284 cubic feet per minute, as a result of reducing the short airway from 14 to 10·61 feet area so that the quantity of air circulating would thus be reduced 10,000 − 8,284 = 1,716 cubic feet per minute. On the other hand as a result of enlarging the longer airway to 18·473 feet area, there would be 5,858 cubic feet passing in each airway if the pressure per square foot is maintained, or a total of 11,716 cubic feet for the two airways, showing in that case an increase of 11,716 − 10,000 = 1,716 cubic feet.

If it were desirable to have the same total quantity passing as before with the same pressure per square foot, then in that case observe that the areas of both airways must be altered. They would then pass 5,000 cubic feet each and the question to solve becomes; if a 14 feet area square airway 400 yards long passes 5,828 cubic feet per minute, what must its area be to pass 5,000 cubic feet if the pressure remain constant? The side of a 14 feet area square airway is $\sqrt{14} = 3\cdot74166$, and therefore the value of the side of the altered airway would be $\left(\frac{5{,}000}{5{,}858}\right)^{\frac{2}{5}} \times 3\cdot74166 = 3\cdot512$ and its area $3\cdot512^2 = 12\cdot334$ which is the area of the 400-yard airway; and similarly for the longer airway the question would become; if a 14 feet area square airway 800 yards long passes 4,142 cubic feet per minute, what must its area be to pass 5,000 cubic feet per minute with the same pressure?

Here $\left(\frac{5{,}000}{4{,}142}\right)^{\frac{2}{5}} \times 3\cdot74166 = 4\cdot0343$ and $4\cdot0343^2 = 16\cdot2755$ as the area of the 800-yard airway.

A check on the accuracy of these figures is given by proportion thus; As 18·473 : 16·2755 : : 14 : 12·334, showing that the relative proportions hold good for any quantities of air.

The questions bearing upon ventilation arising from different pressures have been considered; and it will now be well to give examples on the power producing ventilation. The student must remember that *power* and *pressure* are different things; pressure being the force per square foot producing the ventilation, while power (often expressed by u) is the quantity passing multiplied by the pressure.

The quantity of air passing is according to the cube root of the power applied, and the power necessary to produce ventilation as the cube of the quantity.

Example 23.—If 50,000 cubic feet of air circulate in a mine and it is to be trebled, or the quantity is to be increased to 150,000 cubic feet by increasing the power, the circumstances of the mine remaining unaltered, then the power must be increased 3^3 or 27 times to attain that object.

Example 24.—If 20,000 cubic feet circulate by the expenditure of 64,000 units of work, and the units of work be increased to 343,000 the quantity which would then pass will be found thus:—

As $\sqrt[3]{64{,}000} : \sqrt[3]{343{,}000} : : 20{,}000 : 35{,}000$ cubic feet.

Example 25.—It may be desirable to know the quantity which will circulate by the combined working of a furnace and a fan, or other means when the quantity obtained by each separately is known. Thus, if a mine circulates 20,000 cubic feet of air per minute by the furnace alone, and 30,000 cubic feet by the fan alone, proceed to find the quantity of air that will pass when the two act together as follows:—

As already said, the power required to ventilate a given mine varies as the cube of the quantity. If, therefore, a mine circulated 20,000 cubic feet of air per minute and 1 represent the power used, then when 30,000 cubic feet are circulated, whether by fan or other means, the power will be, As $20{,}000^3 : 30{,}000^3 : : 1 : 3·375$, or it may be put $\frac{30{,}000}{20{,}000} = 1\frac{1}{2}$, and $\left(1\frac{1}{2}\right)^3 = 3·375$. Therefore, it requires 3·375 times more power to circulate 30,000 cubic feet than 20,000 cubic feet. The combined powers would be then $3·375 + 1 = 4·375$, and as the quantity varies as the cube root of the powers, then for both furnace and fan

As $\sqrt[3]{1} : \sqrt[3]{4·375} : : 20{,}000 : 32{,}710$ cubic feet, which is the quantity circulating when the furnace and fan act together.

Example 26.—If two circular airways are each 1,000 yards long, but one of them is 4 feet in diameter, and the other 6, and it is required to know the relative powers for circulating a given quantity through each, say 10,000 cubic feet per minute.

If u represents the power and q the quantity in cubic feet per minute, then $u = \frac{ksv^2q}{a}$ because $u = q \times p$ and the value of u for the 4-foot diameter airway is

$$u = \frac{·0000000217 \times 1{,}000 \times 3 \times 4 \times 3·14159 \times \left(\frac{10{,}000}{4^2 \times ·7854}\right)^2 \times 10{,}000}{4^2 \times ·7854} = 412{,}250$$

units of work, and for the 6-foot diameter airway,

$$u = \frac{·0000000217 \times 1{,}000 \times 3 \times 6 \times 3·14159 \times \left(\frac{10{,}000}{6^2 \times ·7854}\right)^2 \times 10{,}000}{6^2 \times ·7854} = 54{,}288$$

units of work.

If these units of work be taken and the proportion between them ascertained, thus, As 54,288 : 412,250 : : 1 : 7·593, observe that the same proportion exists between the 5th power of the larger airway's diameter and the 5th power of the smaller airway's diameter, thus, As $4^5 : 6^5 :: 1 : 7{\cdot}593$, therefore $\frac{412{,}250}{54{,}288} = \frac{6^5}{4^5}$ or $\left(\frac{6}{4}\right)^5 = 7{\cdot}593$.

From this is obtained the following rule. For circular airways of equal lengths to pass equal quantities of air, the relative powers applied to them must be in inverse proportion to the fifth power of their diameters; thus to pass an equal quantity through a 4-foot diameter and a 6-foot diameter airway it requires $\frac{6^5}{4^5} = \left(\frac{6}{4}\right)^5 = 1{\cdot}5^5 = 7{\cdot}593$ times the power for the 4-foot diameter than for the 6-foot diameter airway. For a 6-foot and an 18-foot diameter airway it would take $\left(\frac{18}{6}\right)^5 = 3^5 = 243$ times the power to pass the same quantity in the 6-foot as in the 18-foot diameter airway.

Example 27.—To find the value of p in the preceding example of a 4-foot and a 6-foot diameter airway, proceed thus, $p = \frac{u}{q}$, that is:—

For the 4-foot diameter airway $p = \frac{412{,}250}{10{,}000} = 41{\cdot}225$ lbs.

and „ „ 6 „ do. $p = \frac{54{,}288}{10{,}000} = 5{\cdot}4288$ lbs.

Example 28.—To ascertain the quantity that would pass in the 6-foot airway with the expenditure of the same power as in the 4-foot airway;

As $\sqrt[3]{54{,}288} : \sqrt[3]{412{,}250} :: 10{,}000 : 19{,}655$ cubic feet, or the quantity which will pass in circular airways with the same power is in inverse proportion to the cube root of the relative power, for taking the cube root of the relative power in *Example* 26, and multiplying it by the quantity there stated to be passing, thus $\sqrt[3]{7{\cdot}593} \times 10{,}000 = 19{,}655$ cubic feet, which agrees with the quantity ascertained in the present example.

Example 29.—Again, if the pressure per square foot of 41·225 lbs. applied in the 4-foot diameter airway were applied to the 6-foot diameter airway, then $v = \sqrt{\frac{pa}{ks}} = \sqrt{\frac{41{\cdot}225 \times 6^2 \times {\cdot}7854}{{\cdot}0000000217 \times 1{,}000 \times 3 \times 6 \times 3{\cdot}14159}} = 974{\cdot}62$, and therefore the quantity passing is $974{\cdot}62 \times 6^2 \times {\cdot}7854 = 27{,}557$ cubic feet, or the quantity passing may be found thus; since the quantity varies as the square root of the pressures; as $\sqrt{5{\cdot}4288} : \sqrt{41{\cdot}225} :: 10{,}000 : 27{,}557$ cubic feet. It is now shown that the quantity which will pass with a constant pressure is in inverse proportion to the square root of the relative power, for $\sqrt{7{\cdot}593} \times 10{,}000 = 27{,}557$ cubic feet as before given.

Example 30.—That the same rules given in *Examples* 26, 28, and 29, for circular airways hold good for square airways may be proved by taking the airway given in *Example* 16 of 5 feet by 5, 8,000 feet long, and passing 6,250 cubic feet per minute. The value of p for this has been shown to be 8·68 lbs. in *Example* 16. Take a square airway 10 feet by 10, 8,000 feet long, and passing 6,250 cubic feet per minute, and the pressure $p = \frac{{\cdot}0000000217 \times 320{,}000 \times 62{\cdot}5^2}{100} =$

$\cdot27125$ and $\dfrac{8\cdot68}{\cdot27125} = 32$ as the ratio between the pressures of the two airways. Now take the sides of the two square airways; divide one into the other and take the 5th power of the remainder; in other words take the 5th power of the ratio between the two lengths of sides forming the airways and the result is 32, thus $\dfrac{10^5}{5^5}$ or $\left(\dfrac{10}{5}\right)^5 = 32$.

Therefore the rule to find the relative powers for square airways of equal length to pass equal quantities of air is to remember that they are in inverse proportion to the fifth power of their sides. Thus to pass an equal quantity through a 5-foot square and a 10-foot square airway it requires $\left(\dfrac{10}{5}\right)^5 = 32$ times the power.

Example 31.—Again, it may be shown that the same rules apply equally to rectangular airways, for take a road 4 feet high by 6 feet wide, 1,000 feet long, and passing 5,000 cubic feet of air per minute. Here $p = \dfrac{\cdot0000000217 \times 20{,}000 \times 208\cdot\dot{3}^2}{24} = \cdot7846$. Now find the value of p for a rectangular road 8 feet high by 12 feet wide to pass the same quantity along the same length of road. $p = \dfrac{\cdot0000000217 \times 40{,}000 \times 52\cdot083^2}{96} = \cdot02452$ and the ratio between the pressures in the two cases is $\dfrac{\cdot7846}{\cdot02452} = 32$. But take either the heights or widths of the two roads and find the ratio between them by dividing one into the other and then take the 5th power of the remainder and the result is 32, thus $\left(\dfrac{8}{4}\right)^5$ or $\left(\dfrac{12}{6}\right)^5 = 32$. It is true that in using the rule for rectangular roads the form of the altered roadway must be similar to the original one, or in other words the rule is not applicable unless the proportion of the width to the height is the same in the altered airway as that prevailing in the original one. Bearing this in mind the relative powers for rectangular airways of similar form and of equal length may be found to pass equal quantities of air by taking the proportion of the fifth power of either the two widths or the two heights of the roads.

Example 32.—If a mine be ventilated by one air current, and with a given power there are obtained 10,000 cubic feet through it, the quantities that would pass if the air be divided into 2, 3, 4, 5 or 10 equal splits, the power remaining the same would be in direct proportion to the area. That is with 2 splits there would be 20,000, with 3 splits 30,000, with 4 splits 40,000, with 5 splits 50,000, and with 10 splits 100,000 cubic feet. This is apparent when the rule to find the quantity that will pass along airways when the power u is given is observed closely. It is, $q = \sqrt[3]{\dfrac{u}{ks}} \times a$. In the case of the 2 splits, 3 splits, &c. the values of u, k, and s, are equal in each case, and only a would vary. It will be seen that this is a very different result from that obtained by splitting the air into a number of currents when the *pressure* remains the same as worked out in *Example* 6.

Example 33.—From the formula $q = \sqrt[3]{\dfrac{u}{ks}} \times a$ is deduced $u = ks \times \dfrac{q^3}{a^3}$ or $ks\left(\dfrac{q}{a}\right)^3$ thus:

$$q = \sqrt[3]{\frac{u}{ks}} \times a$$

$$\therefore q^3 = \frac{u}{ks} \times a^3$$

$$\frac{q^3}{a^3} = \frac{u}{ks}$$

$$u = ks \times \frac{q^3}{a^3} \text{ or } ks \left(\frac{q}{a}\right)^3 \text{ or } ksv^3.$$

Example 34.—The rule to find the horse-power producing the ventilation is to divide the units of work by 33,000. If the quantity of air passing in a mine is 50,000 cubic feet per minute, with a 1·5-inch water-gauge, the horse-power producing the ventilation will be found thus :—$\frac{50{,}000 \times 1{\cdot}5 \times 5{\cdot}2}{33{,}000} = 11{\cdot}82$ horse-power.

Example 35.—If 20,000 cubic feet of air pass in a circular airway of 12 feet diameter, what quantity will pass in one of 6 feet diameter ?

As $\sqrt[3]{\left(\frac{12}{6}\right)^5} : \sqrt[3]{1} :: 20{,}000$ or $\frac{20{,}000}{\sqrt[3]{32}} = 6{,}300$ cubic feet per minute.

Example 36.—If a furnace and steam jet combined produce 50,000 cubic feet of air per minute, and the furnace alone 44,000 cubic feet and it is required to know what the steam jet alone would produce, set down the power of the furnace which alone produces 44,000 cubic feet per minute at 1, then the power of the furnace and steam jet combined will be in the ratio to the power of the furnace as $44{,}000^3 : 50{,}000^3 :: 1 : 1{\cdot}46741$ or $\left(\frac{50{,}000}{44{,}000}\right)^3 = 1{\cdot}46741 : 1$, therefore the power of the steam jet is ·46741. To find the quantity the steam jet alone will produce if a power of 1 produces 44,000 cubic feet proceed thus—As $\sqrt[3]{1} : \sqrt[3]{{\cdot}46741} :: 44{,}000 : 34{,}147$, or say if a power of 1·46741 produces 50,000, what will the power of ·46741 produce, thus—As $\sqrt[3]{1{\cdot}46741} : \sqrt[3]{{\cdot}46741} :: 50{,}000 : 34{,}147$, which is the quantity in cubic feet per minute the steam jet alone will produce.

Example 37.—If by applying 50,000 units of work 40,000 cubic feet of air are produced, and it is desired to know how many units will be required to circulate 75,000 cubic feet, then as $40{,}000^3 : 75{,}000^3 :: 50{,}000 : 329{,}590$.

Examples have already been worked out showing how the area of an air-course alters to pass different quantities of air with the same pressure, and in these examples the power must vary directly with the increased or decreased quantity.

Example 38.—Take for instance that of an aircourse 8,000 feet long, 5 feet by 5, passing 6,250 cubic feet per minute, and it is proposed to enlarge the area so as to pass 22,500 cubic feet per minute, the pressure remaining the same, which is once more using the figures of *Example* 16. The power u would be increased $\frac{22{,}500}{6{,}250} = 3{\cdot}6$ times. That this is so must be evident because $u = p \times q$. In the first case the power would be $8{\cdot}68 \times 6{,}250$ and in the second $8{\cdot}68 \times 22{,}500$. Also take the formula $q = \sqrt[3]{\frac{u}{ks}} \times a$ to find the quantities in each case, and

In the first, $q = \sqrt[3]{\dfrac{8{\cdot}68 \times 6{,}250}{{\cdot}0000000217 \times 160{,}000}} \times 25 = 6{,}250$ cubic feet.

In the second, $q = \sqrt[3]{\dfrac{8{\cdot}68 \times 22{,}500}{{\cdot}0000000217 \times 286{,}080}} \times 71{\cdot}28 = 22{,}500$ cubic feet.

If required to increase the quantity from 6,250 cubic feet per minute without altering the 5 feet by 5 feet airway the power must be increased thus :—

As $6{,}250^3 : 22{,}500^3 :: 1$ or $\left(\dfrac{22{,}500}{6{,}250}\right)^3 = 46{\cdot}656$ times.

In other words, if the quantity were increased by enlarging the airway as indicated from a 25-foot area one to a 6-foot by 11·88 or 71·28-foot area one, then by the consumption of 3·6 times the amount of coals previously consumed there would be an increase in the quantity of air from 6,250 cubic feet per minute to 22,500 cubic feet per minute ; but had it been attempted to increase the quantity of air to the same extent while the airway remained the same the increased consumption of coal would be 46·656 times.

If the airway had been altered from 5 feet by 5 to 6 feet by 11·88, and it became desirable to have the original quantity of 6,250 cubic feet per minute through the altered airway, the consumption of coals necessary to pass this quantity will be found as follows :

The value of p in the original aircourse has been shown to be 8·68 lbs. For the altered aircourse it would be $p = \dfrac{{\cdot}0000000217 \times 286{,}080 \times 87{\cdot}68^2}{71{\cdot}28} = {\cdot}66954$ lb. and since $u = p \times q$, in each case it would be $8{\cdot}68 \times 6{,}250$ and ${\cdot}66954 \times 6{,}250$.

The quantity 6,250 being common to both, the value of u is in direct proportion to $p \therefore \dfrac{8{\cdot}68}{{\cdot}66954} = 12{\cdot}964$ times less coal required with the enlarged airway to pass the same quantity of air.

Again, by allowing the power to remain the same after the alteration in the airway from 5 feet square to 6 feet by 11·88, then the quantity passing along the enlarged airway will be found thus: for the original airway $u = ks\left(\dfrac{q}{a}\right)^3$, and therefore ${\cdot}0000000217 \times 160{,}000 \times \left(\dfrac{6{,}250}{25}\right)^3 = 54{,}250$, and applying $q = \sqrt[3]{\dfrac{u}{ks}} \times a$ to the altered airway $\sqrt[3]{\dfrac{54{,}250}{{\cdot}0000000217 \times 286{,}080}} \times 71{\cdot}28 = 14{,}682$ cubic feet per minute, and the velocity would be $\dfrac{14{,}682}{71{\cdot}28} = 205{\cdot}977$ feet per minute, and in that case the value of p for the altered airway is $= \dfrac{{\cdot}0000000217 \times 286{,}080 \times 205{\cdot}977^2}{71{\cdot}28} = 3{\cdot}695$ lbs. as compared with 8·68 lbs. pressure for the original airway to pass 6,250 cubic feet per minute.

It must be borne in mind that the examples which have been worked out refer entirely to the overcoming of frictional resistances, because for simplicity the pressure necessary for velocity need not be considered—it is so little. The velocity of air without resistance is the same that a body would attain in falling the height of the motive column, so that if there is a difference of pressure equal to 36 feet of air column, the theoretical velocity of the air would be $8\sqrt{M}$, where M = motive column in feet or $8\sqrt{36}$ = equal 48 feet per second, because a falling body under the force of gravity would attain a velocity of 8 times the square root of 36 or 48 feet. The co-efficient of friction ·0000217 lb. per square foot of area of section is applicable only to the underground roadways. That for the shafts of different forms has not been definitely fixed by experiment. It is usual, however, to take ·00001 lb. per square foot for circular shafts, where the smooth surface gives little impediment to the passage of air.

As a further assistance questions with answers are now submitted and worked out, bearing on the subject of ventilation.

Question 82.—There are 6,000 cubic feet of air passing, what power will be required to pass 12,000 cubic feet, the airway remaining in the same state?

The velocity of the air will be doubled, necessitating four times the pressure on each square foot of area because the friction varies as the square of the velocity. Also this increased pressure per square foot has to be sustained at a double velocity, hence the power varies as the cube of the quantity. In this case the double quantity will require $2^3 = 8$ times the power.

Question 83.—A certain number of shots have to be fired in a mine, how should a fireman be instructed to proceed? What other duties has he to attend to?

In such cases a fireman should fire the shots in succession, beginning at the return side and travelling in the direction contrary to that of the current, so that any fire-damp liberated by a shot may not be exploded by the firing of a succeeding shot. His duties are to keep the airways free from all obstructions that would impede the circulation of the air. Further he should see that the regulators are in good condition, properly adjusted and locked; that all doors in use are made to fall to or close themselves without leakage of air, and that those not in use are taken off their hinges; that the roof and sides of the airways are safely timbered or walled up; that all projecting or loose stones are removed or timbered, so that the road may be safe to travel in; that all stoppings, air-crossings and brattices are in good order and do not allow the air to escape; he should examine all cavities in the roof and open spaces in the goaves for gas, and if gas be present adopt means to remove it. If there are any special features in the Colliery, such as gob fires, blowers of gas, &c., the fireman should receive special instructions concerning them.

Question 84.—The total quantity of air passing over a furnace is 200,000 cubic feet per minute, burning 5 tons of coal per 12 hours, how much increase of air would be obtained by adding 5 more tons of coal for the 12 hours to the furnace?

The power increases in the same ratio as the coals burned are increased, which in this case is as 1 : 2, and as the quantity of air increases in direct proportion to the cube root of the powers, then as $\sqrt[3]{1} : \sqrt[3]{2} ::$ 200,000, or as 1 : 1·25992 :: 200,000 : 251,984, which is the quantity circulating after the power is added to, therefore the net increase is 251,984 − 200,000 = 51,984 cubic feet.

Question 85.—A regulator is placed in the return airway of a district and a blower of gas is discovered in that return airway which comes against the air through the regulator. It is impossible to add more air to that district, how then must the gas be prevented from finding its way into the district?

Under such unusual circumstances, reduce the area of the regulator until the velocity of the air is sufficient to resist the pressure of the gas, and as this act by itself will reduce the quantity of air in that district, if practicable enlarge the airway or provide an additional one on the outbye side of the blower. If this does not meet the case, additional aircourses must be devised.

Question 86.—If one ventilating fan produces 25,000 cubic feet of air per minute what total quantity of air will be given if another fan of the same dimensions be added to it and worked with an equal power?

As $\sqrt[3]{1} : \sqrt[3]{2}$ :: 25,000, or as 1 : 1·25992 :: 25,000 : 31,498 cubic feet per minute.

Question 87.—What is the general efficiency of fans? If the horse-power of an engine is 40, and the water-gauge is 1·5 inch, what quantity of air would you expect to get?

The general result obtained from a fan is about 50 per cent. of the indicated horse-power of the engine, realised in useful work done on the air. With an engine of 40 indicated horse-power the horse-power in the air therefore would be as 100 : 50 :: 40 : 20, and as the rule is; horse-power in the air = $\frac{\text{Quantity in cubic feet per minute} \times \text{water-gauge} \times 5{\cdot}2}{33{,}000}$ ∴ the quantity = $\frac{\text{H. P} \times 33{,}000}{\text{water-gauge} \times 5{\cdot}2}$ ∴ $\frac{20 \times 33{,}000}{1{\cdot}5 \times 5{\cdot}2} = 84{,}615$, which is the quantity in cubic feet per minute we may expect to get.

Question 88.—The temperature in the downcast is 50° F., that in the upcast is 100° F. What would be the increase in the velocity of the air by doubling the depth of the pits, the temperature remaining the same?

The power of a furnace consists in the difference it can produce between the pressures per square foot at the bottom of the two shafts, multiplied by the velocity at which this difference is maintained, and as the said difference of pressure depends on the difference between the weights of a cubic foot of air in the two shafts multiplied by the depth of the upcast shaft, therefore if the temperature in the shafts remains constant, so also will the weight of given volumes of air, and hence the pressure produced by the furnace will then vary as the depth of the upcast shaft.

By doubling the depth of the upcast shaft the pressure produced will be doubled, and as the velocity varies as the square root of the pressure giving rise to it, the velocity will be increased $\sqrt{2} = 1{\cdot}4142$ times. The power of the furnace would be $1{\cdot}4142 \times 2 = 2{\cdot}8284$ times as great in the latter case. The quantity of coals consumed will be a little more than 1·4142 times for the quantity of air to be heated is increased to that extent, and the initial temperature will need to be higher in the last case to get the same average temperature in the deeper shaft. This is disregarding the extra friction added by lengthening the upcast shaft, which would reduce the quantity, and this may or may not be to a serious extent according as the shaft friction is or is not a large proportion of the friction of the whole mine.

Question 89.—A barometer registers 30 inches at the surface, what will it register at a point 1,890 feet below the surface?

By the formula given under the remarks on barometer in Chapter X., $I = \frac{D \times B}{26{,}216}$; $I = \frac{1{,}890 \times 30}{26{,}216} = 2{\cdot}16$, therefore the barometer would register $30 + 2{\cdot}16 = 32{\cdot}16$ inches at a point 1,890 feet below the surface. Or say that a barometer rises $\frac{1}{10}$th of an inch for every 88 feet of descent. Therefore $\frac{1890}{88} = 21{\cdot}5$, which divided by 10 gives 2·15 as the rise of the barometer for the depth given, almost as before.

Question 90.—Give the size of two airways whose perimeters are equal; the area of one being one and a half times larger than that of the other.

Here 9 feet × 6 feet = 30 feet perimeter and area 54 feet.
12 „ × 3 „ = 30 „ „ „ 36 feet and
$36 \times 1\frac{1}{2} = 54$ feet.

Question 91.—How much more resistance will a current of 600 feet per minute meet with than one 500 feet per minute, the aircourse being the same? The latter has a water-gauge of ·76 inch, what will that of the former be?

The resistance is as the square of the velocity while the aircourse remains the same, therefore if the velocity be increased from 500 feet to 600 feet per minute the resistance will be as $5^2 : 6^2 = \frac{36}{25} = 1{\cdot}44$ times greater, and the water-gauge would be $\cdot76 \times 1{\cdot}44 = 1{\cdot}0944$ inch.

Question 92.—The quantity of air which must be made to flow in a new mine is 116,640 cubic feet per minute. What size ought the shaft to be for the air to have a mean velocity in the shaft of $7\frac{1}{2}$ feet per second.

Here $7\frac{1}{2}$ feet per second = 450 feet per minute and $\frac{116{,}640}{450} = 259{\cdot}2$ square feet area of shaft. Its diameter therefore is $\sqrt{\frac{259{\cdot}2}{\cdot7854}} = 18{\cdot}166$ or 18 feet 2 inches.

Question 93.—There are two airways; the first is 8 feet square, the second 10 feet by 4. The same quantity of air is wanted to be passed in each airway; the water-gauge stands at ·2 inch in the first, what will it register in the second case?

By Atkinson's formula $p = \frac{ksv^2}{a}$, and as k is common to both airways omit it and for s substitute the value of o. The relative velocities will be in proportion to the areas of the roads, viz., as 40 : 64, or as 5 : 8. The value of p in the two roadways will then be in the following proportion:—

As $\frac{32 \times 5^2}{64} : \frac{28 \times 8^2}{40} = 12{\cdot}5 : 44{\cdot}8$, and therefore the pressure in the smaller airway is $\frac{44{\cdot}8}{12{\cdot}5} = 3{\cdot}584$ times that of the larger, and the water-gauge in the larger being ·2 inch, that of the smaller is $\cdot2 \times 3{\cdot}584 = \cdot7168$ inch.

Question 94.—What horse-power would an engine exert when yielding 60 per cent. of duty to move 100,000 cubic feet of air a minute; the water-gauge stands at 1 inch?

$$\frac{100{,}000 \times 5{\cdot}2}{33{,}000} = 15{\cdot}75 \text{ horse-power effective } \therefore$$

As 60 : 100 :: 15·75 : 26·25 horse-power exerted by engine.

Question 95.—In an airway 10 feet by 6 passing 30,000 cubic feet of air per minute, with a velocity of 500 lineal feet per minute, the water-gauge stands at ·5 inch. What will the water-gauge show if the same quantity be passed through an airway 8 feet by 5?

The perimeters are 32 and 26; therefore, the rubbing surface is as 16 : 13; and the areas are 60 and 40 feet, or in the proportion of 3 to 2. The velocity in the small airway would be as 2 : 3 :: 500 : 750 feet per minute. The pressures, then, would be in proportion thus: as $\frac{16 \times 5^2}{60} : \frac{13 \times 7{\cdot}5^2}{40}$ or as 6·6 : 18·28, and therefore the pressure in the smaller airway is $\frac{18{\cdot}28}{6{\cdot}6} = 2{\cdot}744$ times more than that of the larger, and the water-gauge of the larger being ·5, that of the smaller would be $\cdot 5 \times 2{\cdot}744 = 1{\cdot}372$ inch to pass equal quantities of air.

Question 96.—20,000 cubic feet of air per minute are required through an airway 4,000 feet long by the application of 5 horse-power. Of what area must it be to give the desired result, (*a*) if square, (*b*) if circular, and (*c*) if rectangular, supposing the seam to be 6 feet high?

By Atkinson's formula $a = \frac{ksv^2}{p}$, and in the case of a square airway if a be its area, then its perimeter is $4\sqrt{a}$, and as the quantity of air is found by multiplying the area by the velocity, $v = \frac{q}{a}$ where q represents the quantity. For $a = \frac{ksv^2}{p}$, then substitute $a = \frac{k(4\sqrt{a}\,l) \times \left(\frac{q}{a}\right)^2}{p}$; l, being the length of air-course in feet. By collecting terms $\frac{a^3}{\sqrt{a}} = \frac{4\,k\,l\,q^2}{p}$, and by squaring both sides $\frac{a^6}{a} = \left(\frac{4\,k\,l\,q^2}{p}\right)^2 \therefore a^5 = \left(\frac{4\,k\,l\,q^2}{p}\right)^2$ and $a = \left(\frac{4\,k\,l\,q^2}{p}\right)^{\frac{2}{5}}$.

Since the power is the quantity passing multiplied by the pressure $a = \left(\frac{4\,k\,l\,q^3}{pq}\right)^{\frac{2}{5}} = \left(\frac{4\,k\,l\,q^3}{u}\right)^{\frac{2}{5}}$ where u is the power expressed in units of work.

Substituting the known values in the equation, thus

$$a = \left(\frac{4 \times \cdot 0000000217 \times 4{,}000 \times 20{,}000^3}{33{,}000 \times 5}\right)^{\frac{2}{5}} = 49{\cdot}0314$$ square feet as the area, or rather more than 7 feet square.

In the case of a circular airway, if a represent its area, the perimeter will be $3{\cdot}545\sqrt{a}$, and the formula will be $a = \left(\frac{3{\cdot}545\,k\,l\,q^2}{p}\right)^{\frac{2}{5}}$ or $\left(\frac{3{\cdot}545\,k\,l\,q^3}{u}\right)^{\frac{2}{5}}$, and substituting the known values in this equation

$$a = \left(\frac{3{\cdot}545 \times \cdot 0000000217 \times 4{,}000 \times 20{,}000^3}{33{,}000 \times 5}\right)^{\frac{2}{5}} = 46{\cdot}72;$$ or, knowing the size of the square airway, proceed to find the size of a circular one to pass the same quantity, thus:—

The perimeter of the square airway is $7 \times 4 = 28$ feet, and $R = \sqrt{\frac{49^3}{28}}$.

Therefore, $\sqrt{\frac{49^3}{28}}$ or omitting the sign of the square root, since the value of R is the same in each case, $\frac{49^3}{28} = 4{,}201{\cdot}75$. Then, as per *Example* 16, but allowing for the square root sign removal, the area a of the circular airway is $= \sqrt[5]{12{\cdot}567\ R^2}$. $\therefore a = \sqrt[5]{12{\cdot}567 \times 4201{\cdot}75^2} = 46{\cdot}7$ as before.

In the case of a rectangular road whose height is given as 6 feet let $x =$ the

width of the road in feet. Then $6x =$ its area, and $12 + 2x$ its perimeter. Substituting these in the formula $a = \frac{ksv^2}{p}$

$$6x = \frac{kl\ (12 + 2x) \times \left(\frac{q}{6x}\right)^2}{p},$$

dividing both sides by $\left(\frac{q}{6x}\right)^2$,

$$\frac{6x}{\frac{q^2}{36x^2}} = \frac{kl(12 + 2x)}{p},$$

$$\therefore \frac{216x^3}{q^2} = \frac{kl\ (12 + 2x)}{p},$$

$$216x^3 = \frac{klq^2\ (12 + 2x)}{p},$$

$$x^3 = \frac{12\ klq^2 + 2\ klq^2x}{216\ p} \text{ or } \frac{12\ klq^3 + 2\ klq^3x}{216\ u}.$$

Now substitute the known values of $k\ l\ q$ and u, thus

$$x^3 = \frac{\{12 \times \cdot 0000000217 \times 4{,}000 \times (20{,}000)^3\} + \{2 \times \cdot 0000000217 \times 4{,}000 \times (20{,}000)^3 x\}}{216 \times 33\,000 \times 5}$$

$$x^3 = \frac{8{,}332{,}8000{,}00 + 1{,}388{,}800{,}000\ x}{35{,}640{,}000},$$

$$x^3 = 38 \cdot 9\ x + 233 \cdot 8,$$

$$x^3 - 38 \cdot 9\ x - 233 \cdot 8 = 0.$$

Or the same cubic equation may be obtained another way.

Knowing the size of the square airway, proceed to substitute a rectangular one or it to pass the same quantity; thus $R = \frac{(6x)^3}{12 + 2x}$, and therefore, as shown in *Example* 16, but allowing for the sign of the square root there used and now omitted, $x^3 = \frac{12\ R + 2\ R\ x}{216}$, and substituting the known value of R

$$x^3 = \frac{(12 \times 4{,}201 \cdot 75) + (2 \times 4{,}201 \cdot 75\ x)}{216},$$

$$x^3 = \frac{8{,}403 \cdot 5\ x + 50{,}421}{216} = 38 \cdot 9\ x + 233 \cdot 4,$$

$$x^3 - 38 \cdot 9\ x - 233 \cdot 4 = 0.$$

Proceed to work out this cubic equation by the trigonometrical formula,

$$x^3 - px - Q = 0$$

$$\text{Sin. } a = \frac{p}{3\ Q}\ 2 \sqrt{\frac{p}{3}}$$

$$\text{Tan. } \beta = \sqrt[3]{\text{tan. } \tfrac{1}{2}\ a}$$

$$x = \frac{2 \sqrt{\frac{p}{3}}}{\text{Sin. } 2\ \beta}$$

Substituting the values of p and Q in the formula,

$$\text{Sin. } a = \frac{38 \cdot 9}{700 \cdot 2} \times 2 \times \sqrt{\frac{38 \cdot 9}{3}}$$

$$a = 23^\circ\ 36'$$

$$\text{and } \tfrac{1}{2}\ a = 11^\circ\ 48'$$

$$\text{Tan. } \beta = \text{tan. } \sqrt[3]{11^\circ\ 48'}$$

$$\text{Log. tan. } 11^\circ\ 48' = 9{\cdot}319961$$
$$\text{less } 10$$
$$\text{divide by 3 to cube root } \big)\ \overline{1}{\cdot}319961$$
$$\overline{1}{\cdot}773320$$
$$\text{add } 10$$
$$9{\cdot}773320$$
$$= \text{log. tan. of } 30^\circ\ 41'$$
$$2\,\beta = 61^\circ\ 22'$$
$$x = \frac{2\sqrt{\frac{38{\cdot}9}{3}}}{\text{Sin. } 61^\circ\ 22'}$$
$$x = 8{\cdot}3$$

The size of the rectangular road to pass the required quantity therefore is 6 feet × 8·3, or 49·8 square feet area.

Question 97.—The temperature of the air in the downcast is 60° F., and in the upcast 100° F.; the quantity of air entering the mine by the downcast is 20,000 cubic feet per minute, and the size of each shaft is 15 feet in diameter. What will be the velocity of air in feet per minute in each pit respectively?

The velocity in the downcast would be $\frac{20{,}000}{15^2 \times {\cdot}7854} = 113{\cdot}176$ feet per minute. Since 460 cubic feet of air at 0° expand a cubic foot for each degree of heat (Fahrenheit) added, therefore 460 cubic feet at 0° become 460 + 60 = 520 cubic feet at 60° and 460 + 100 = 560 cubic feet at 100°. Therefore, as 520 : 560 :: 20,000 : the volume occupied by 20,000 cubic feet at 100°, or since the areas of the upcast and downcast are the same, the velocity in the downcast may be proportioned to that in the upcast thus:—As 520 : 560 :: 113·176 : 121·88, which is the velocity in the upcast shaft.

Question 98.—How far can you drive a pair of levels without showing a "cap" in the safety-lamp at the upcast? The current of air is 4,000 cubic feet per minute, and assuming that the coal gives off 1 cubic foot of fire-damp for every 30 yards of each level, give the proportions of air and gas in the mixture.

Light carburetted hydrogen gas can be detected by the lamp when it exists in the air in the proportion of 1 in 30. In 30 yards of the level the quantity of gas in the air will be one-four-thousandth. ∴ As 30 : 4,000 :: 30 : 4,000, but as there is a pair of levels divide by 2 = 2,000. That is, the levels can be driven 2,000 yards from the pit before the return air will show a cap on the flame at the upcast if there is no change in the quantity of gas emitted during the driving. The proportions of the mixture at the upcast will be $\frac{1}{30}$th of gas in the air current.

Question 99.—A pair of winning places 100 yards long each have stentons connecting them 20 yards apart, the winning places being separated by 10 yards of coal. The winning places and stentons are all filled with undiluted gas CH_4; current of air passing 6,000 feet per minute. What is the least possible time to clear this gas out without fouling the air, except with small cap on top of a safety-lamp? Places all are 8 feet wide and 5 feet high.

Here $\frac{100}{20} = 5$ stentons 10 yards long $= 50$ yards, and the winning places 100 $\times 2 = 200$ yards. $200 + 50 = 250 \times 3 \times 40$ the area $= 30{,}000$, which is the total number of cubic feet of undiluted gas.

If $\frac{1}{30}$th be taken as the proportion of gas that shows a slight cap on the safety lamp flame, the quantity of gas that can be taken away per minute will be $\frac{6{,}000}{30}$ $= 200$ cubic feet, $\therefore$ the time occupied in removing the whole will be $\frac{30{,}000}{200} =$ 150 minutes $= \frac{150}{60} = 2\frac{1}{2}$ hours.

Question 100.—An explosive mixture of air and gas at the highest explosive point passes along an airway 4 feet by 5 at a velocity of 500 feet per minute. What quantity of fresh air must be added so that you cannot detect it on the flame of a safety lamp?

Here the area of the airway is $4 \times 5 = 20$ feet $\times 500 = 10{,}000$ feet of air and gas. When at the highest explosive point the mixture is 1 of gas to 8 or 9 of air, but taking it at one of gas to 9·5 of air, as proportioned by some, then

As 10·5 : 9·5 :: 10,000 : 9,047·6 cubic feet of air,
and as 10·5 : 1 :: 10,000 : 952·4 ,, ,, firedamp.

When the mixture is 31 of air to 1 of the gas its presence cannot be detected, so that $952{\cdot}4 \times 31 = 29{,}524$ cubic feet as the quantity of air required, but as there are already 9,047 cubic feet of air it would take an additional quantity of $29{,}524 - 9{,}047 = 20{,}477$ cubic feet per minute of fresh air to dilute the gas so that it could not be detected by means of the lamp.

Question 101.—How long would it take an air-current of 20,000 cubic feet per minute to make the circuit of an airway 4,000 yards long, 10 feet by 10 feet?

10 feet $\times$ 10 feet $=$ 100 feet sectional area, and $\frac{20{,}000}{100} = 200$ feet per minute as the velocity of the current. $\therefore \frac{4{,}000 \times 3}{200} = 60$ minutes or 1 hour to make the circuit.

Question 102.—A current of 2,000 cubic feet a minute is at explosive point. How much fresh air must be mixed with it to prevent its showing a "cap"?

When the firedamp forms as much as one part out of thirteen of an air-and-gas mixture it becomes explosive.

The gas evolved, therefore, would be $\frac{1}{13}$ of $2{,}000 = 153{\cdot}846$ cubic feet per minute, and the quantity of air is $2{,}000 - 153{\cdot}846 = 1{,}846{\cdot}154$. In a mixture of one part of firedamp to 30 of air the flame will not show a cap. $153{\cdot}846 \times 31 = 4{,}769$ cubic feet per minute as the total ventilation, when the requisite change has taken place. Then the fresh air required to accomplish this will be 4,769 cubic feet, but as already 1,846 cubic feet of fresh air are passing, an additional quantity of $4{,}769 - 1{,}846 = 2{,}923$ cubic feet per minute will be required.

Question 103.—The depth of downcast is 100 fathoms, with a temperature of 50° F., the depth of upcast is 150 fathoms, with a temperature of 100° F. What water-gauge should this show?

Here the state of the barometer is not given, but, assuming it to be 30 inches, the weight of a cubic foot in the downcast would be $\frac{1{\cdot}3253 \times 30}{459 + 50} = {\cdot}07811$ lb.; that of the upcast would be $\frac{1{\cdot}3253 \times 30}{459 + 100} = {\cdot}07112$ lb.; and the difference is ${\cdot}07811 - {\cdot}07112 = {\cdot}00699$. The depth of the upcast being 900 feet gives ${\cdot}00699 \times 900 = 6{\cdot}291$ lbs. as the pressure due to the difference in the mere weight of the two columns. The water-gauge would therefore read $\frac{6{\cdot}291}{5{\cdot}2} = 1{\cdot}21$ inch, and the motive column is as ${\cdot}07811 : 900 :: {\cdot}00699 : 80{\cdot}54$ feet.

Question 104.—In a colliery with two shafts, one downcast and the other upcast, each 1,000 feet deep and 15 feet in diameter, temperature of downcast 60° F., average pressure in the shafts 30 inches. Quantity of air going down the downcast, 150,000 cubic feet per minute, the ventilation being produced by a furnace. Required the average temperature of the upcast, and total horse-power necessary to produce the ventilation, assuming that of the workings (total, minus shafts) to be 50 horse-power.

By using the formula $u = ks\left(\frac{q}{a}\right)^3$ to find the power necessary to circulate 150,000 cubic feet of air per minute through the two shafts, it gives ${\cdot}0000000217 \times (15 \times 3{\cdot}14159 \times 2{,}000) \times \left(\frac{150{,}000}{15^2 \times {\cdot}7854}\right)^3 = 1{,}250{,}792$ units of work. $\therefore \frac{1{,}250{,}792}{33{,}000} = 37{\cdot}9$ horse-power. But, as stated before, the value of k has not been fixed for shafts, and it is manifestly unfair to assume it will be the same for them as for the rough and uneven passages of a mine; probably the value for the smooth surfaces of the shafts will not exceed one-half that of the underground roads.

Assume the power used in the two shafts to be 20 horse-power instead of the above worked-out 37·9, then the total horse-power required for both shafts and mine will be $20 + 50 = 70$, and $70 \times 33{,}000 = 2{,}310{,}000$ foot pounds or units of work. That is, the furnace must be capable of performing that work per minute.

At a temperature of 60° F., and barometer at 30 inches, a cubic foot weighs $\frac{1{\cdot}3253 \times 30}{459 + 60} = {\cdot}0766$ lb., and as there are 150,000 cubic feet of air circulating, its weight at the stated temperature and pressure is ${\cdot}0766 \times 150{,}000 = 11{,}490$ lbs. Therefore, the duty of the furnace is to lift this weight of air through a height of $\frac{2{,}310{,}000}{11{,}490} = 201$ feet in one minute. Proceed to find the temperature that must be maintained in the upcast shaft to circulate the air through both the shafts and mine, by the formula

$$T = \frac{h\,(459 + t)}{l - h} + t$$

where h = the height through which the whole of the air which traverses the mine has to be lifted

t = the temperature of the downcast shaft

T = do. do. upcast do.

l = the length of the heated column of air in the upcast.

Substituting the known values in the above formula $T = \frac{201 \times (459 + 60)}{1{,}000 - 201} + 60 = 190°$.

A column of air 1,000 feet high, and at a temperature of 190° F., in the upcast shaft, would occupy a height represented by x when cooled down to 60° F. $1{,}000 \times \dfrac{459 + 60}{459 + 190} = 799$; or $x\left(1 + \dfrac{190 - 60}{459 + 60}\right) = 1{,}000$, and so $x =$ 799. Therefore $x = l - h$. The value of h is the height of a column of air which will balance the difference of weight between the two volumes of air in the downcast and upcast, usually called the motive column.

Question 105.—If 40,000 cubic feet of air enter a downcast shaft 14 feet diameter, and the temperature is 60° F., what must be the diameter of the upcast shaft to pass that quantity of air, the velocity being the same in each case, and the temperature of the upcast being 100° F.?

The sectional area of the downcast is $14^2 \times \cdot 7854 = 153 \cdot 9384$ square feet. $\therefore \dfrac{40{,}000}{153 \cdot 9384} = 259 \cdot 8442$ feet per minute as the velocity of the current in the downcast.

The velocity in the upcast would be, therefore, $259 \cdot 8442 \times \dfrac{460 + 100}{460 + 60} = 279 \cdot 83$ when both shafts have the same diameter. Hence $\sqrt{\dfrac{279 \cdot 83 \times 153 \cdot 9384}{259 \cdot 8442 \times \cdot 7854}} =$ 14·528 feet diameter of the upcast when the velocity of the current is the same in both shafts.

Question 106.—If 30,000 cubic feet of air entered a shaft 14 feet diameter, at a temperature of 60° F., what diameter of upcast is necessary to pass the same quantity, the velocity being the same in each case, and temperature of upcast 90° F.?

A volume of air increases $\frac{1}{460}$ of its bulk for each F. degree of increased temperature. The diameter varies as $\sqrt{q}$, or it may be found by $d = \sqrt{\dfrac{D^2 \times Q}{q}}$ where $D =$ diameter of downcast, $d =$ diameter of upcast, $Q =$ quantity in the upcast, $q =$ quantity in the downcast.

Taking the former formula, $\dfrac{30{,}000}{1} \times \dfrac{460 + 90}{460 + 60} = \dfrac{16{,}500{,}000}{520} = 31{,}730$ cubic feet to pass up the upcast shaft, and as $\sqrt{30{,}000} : \sqrt{31{,}730} :: 14 : 14 \cdot 398 =$ diameter of upcast shaft. Or by the latter formula $14^2 = 196 \times 31{,}730 = 6{,}219{,}080 \div 30{,}000 = 207 \cdot 3$ and $\sqrt{207 \cdot 3} = 14 \cdot 398$, as before.

Question 107.—Supposing the existence of an airway passing 20,000 cubic feet of air per minute, what would be the increased quantity after putting in an additional airway of the same dimensions, the power remaining the same?

By the formula $u = ks\left(\dfrac{q}{a}\right)^3$, assuming any value for a, say 30 feet, and s say 1,000 feet.

Then $u = \cdot 0000000217 \times 1{,}000 \times \left(\dfrac{20{,}000}{30}\right)^3 = 6{,}429 \cdot 7$.

After putting in the additional airway, the units of work are to remain the same as before, but the value of a and of s will be doubled, therefore

$q = \sqrt[3]{\dfrac{6{,}429 \cdot 7}{\cdot 0000000217 \times 2{,}000}} \times 60 = 31{,}748$, which is the number of cubic

feet per minute circulating after putting an additional airway of the same dimensions as the original one.

Or $q = \sqrt[3]{\frac{u}{ks}} \times a$.

The value of u, s, and a, may be set down at 1 each when 20,000 cubic feet pass, and the altered conditions will then necessitate u being made 1, and s and a 2 each. The value of k may be omitted, as it is common to both airways, and will not affect the result. The quantity that would pass then is as $\sqrt[3]{\frac{1}{1}} \times 1 : \sqrt[3]{\frac{1}{2}} \times 2 :: 20{,}000$. $\therefore 1 : \cdot 7937 \times 2 :: 20{,}000$, and $20{,}000 \times \cdot 7937 \times 2 = 31{,}748$.

Question 108.—A steam jet and fan, both acting together in an upcast shaft, produce 50,000 cubic feet of air per minute; when the fan is stopped the jet gives 10,000 alone; what would be the result were the jet removed?

The power required to ventilate a given mine varies as the cube of the quantity; if therefore the power of the steam jet which gives 10,000 cubic feet is set down at 1, then the power of the two combined which produces 5 times the quantity will be in the ratio to the power of the steam jet as $5^3 : 1^3$ or as $125 : 1$. Therefore the power of the fan is 124, that of the steam jet being 1. To find the quantity the fan alone will produce—if a power of 1 will produce a quantity of 10,000 what quantity will a power of 124 produce? or, if a power of 125 produce a quantity of 50,000 what will be produced by a power of 124? It is equally true that the quantity varies as the cube root of the power; therefore, As $\sqrt[3]{1} : \sqrt[3]{124} :: 10{,}000 : 49{,}866$,

or, as $\sqrt[3]{125} : \sqrt[3]{124} :: 50{,}000 : 49{,}866$;

that is, the fan alone would give 49,866 cubic feet per minute.

Question 109.—There are two airways in a mine whose lengths are 2,000 feet and 3,000 feet respectively, subject to the same ventilating pressure. The shorter is 5 feet × 5, what size must the longer be made so that each may pass an equal quantity?

Here it is possible to proceed by the formula $R = \sqrt{\left(\frac{a^3}{s}\right)}$ but a simpler way of getting the same result is to remember that the side of the square airway will vary in the proportion of the 5th root of the lengths, when the roads are subject to the same pressure and are to pass the same quantities; thus, As $\sqrt[5]{2{,}000} : \sqrt[5]{3{,}000} :: 5$; or,

As $\sqrt[5]{2} : \sqrt[5]{3} :: 5 : 5 \cdot 42235$ as the side of the longer airway and its area would therefore be $5 \cdot 42235^2 = 29 \cdot 4$.

Similarly for a circular airway the diameter varies in the same ratio. Thus if the airways were circular in form, the diameter of the shorter would be $\sqrt{\frac{25}{\cdot 7854}} = 5 \cdot 6419 \therefore \sqrt[5]{2} : \sqrt[5]{3} :: 5 \cdot 6419 : 6 \cdot 1185$ as the diameter of the 3,000-foot airway and its area therefore would be $6 \cdot 1185^2 \times \cdot 7854 = 29 \cdot 402$ the same as that already worked out for the square airway.

So also for a rectangular airway the height and the width of the airway vary in the same ratio. Thus if the airway had been rectangular and 4 feet high, its width would be $\frac{25}{4} = 6 \cdot 25$ feet. For the 3,000-foot airway then As $\sqrt[5]{2} : \sqrt[5]{3} :: 4 : 4 \cdot 3379$ which is the height of the longer airway : $\sqrt[5]{2} : \sqrt[5]{3} :: 6 \cdot 25$: or put it as $4 : 4 \cdot 3379 :: 6 \cdot 25 : 6 \cdot 7779$ as the width of the longer airway, and therefore the area would be $4 \cdot 3379 \times 6 \cdot 7779 = 29 \cdot 4$ as before.

Airways passing equal quantities subject to the same pressure must have an equal ventilating power, whether their lengths be equal or not.

The answer to this question may be found by assuming any quantity, say, 2,500 cubit feet per minute to be passing along each airway.

Then proceeding by the formula

$$u = ks \times \left(\frac{q}{a}\right)^3 \text{ for the short airway}$$

$$u = \cdot 0000000217 \times 40{,}000 \times 100^3$$

$$u = 868$$

If a = the area of the long airway then $4\sqrt{a}$ or $\sqrt{16a}$ = its perimeter

Then since $\sqrt[3]{\frac{u}{ks}} \times a = q$

$$\sqrt[3]{\frac{868}{\cdot 0000000217 \times 3{,}000 \times \sqrt{16a}}} \times a = 2{,}500$$

$$\therefore \frac{868a^3}{\cdot 0000000217 \times 3{,}000 \times \sqrt{16a}} = 15{,}625{,}000{,}000$$

$$\frac{868a^3}{\sqrt{\cdot 0000000678a}} = 15{,}625{,}000{,}000$$

$$\frac{753{\cdot}424a^6}{\cdot 0000000678a} = 244{,}140{,}625{,}000{,}000{,}000{,}000$$

$$11{,}112{,}448{,}377{,}581a^5 = 244{,}140{,}625{,}000{,}000{,}000{,}000$$

$$a^5 = 21{,}970{,}102.$$

$a = 29{\cdot}4$ being the same result as obtained in the previous working.

Question 110.—There are three airways in a colliery

A,	being	3,000 feet long and	6 feet × 5 feet = 30	feet area
B,	,,	4,000 ,, ,,	6 feet × 6 feet = 36	do.
C,	,,	2,000 ,, ,,	5 feet × 5 feet = 25	do.

The total quantity of air passing in the three airways is 50,000 cubic feet per minute. What is the quantity passing along each?

These airways must be subject to a common pressure and the relative volume for each will be found by the formula $R = \sqrt{\left(\frac{a^3}{s}\right)}$ $\therefore$

$$\text{For A, } R = \sqrt{\frac{30^3}{66{,}000}} = \cdot 6396$$

$$\text{,, B, } R = \sqrt{\frac{36^3}{96{,}000}} = \cdot 69714$$

$$\text{,, C, } R = \sqrt{\frac{25^3}{40{,}000}} = \cdot 625$$

Total relative volumes 1·96174

Therefore the actual volumes going into each must be

For	A	As	1·96174 :	·6396	:: 50,000 :	16,302	cubic feet
,,	B	,,	1·96174 :	·69714	:: 50,000 :	17,768	do
,,	C	,,	1·96174 :	·625	:: 50 000 :	15,930	do
					Total	50,000	do.

Question 111.—Compare the friction in the following roads:—No. 1 is 8 feet by 5; No. 2 is 6 feet by 12; (*a*) for the same quantity and (*b*) for three times the quantity of air.

First, by the formula $R = \sqrt{\left(\frac{a^3}{s}\right)}$, or as R must be the same in each case, omit the sign of the square root, and the result is not affected. Therefore, there are, as the relative resistances in the two roads for the same quantity of air, As $\frac{40^3}{26} : \frac{72^3}{36}$, or as 2,461·5 : 10,368 :: 1 : 4·212; that is, the resistance offered by No. 1 airway will be 4·212 times as great as that offered by No. 2 airway for the same quantity of air.

If 3 times the quantity of air is to circulate through No. 2 as compared with No. 1, then proceed by the formula $u = ks\left(\frac{q}{a}\right)^3$ or ksv^3 to find the relative resistances.

The value of k will be the same in each case, and being a common factor, may be omitted, and the relative resistances then becomes sv^3. There being no definite quantity of air assigned as passing through the airways for convenience make the quantity passing through No. 1 a multiple of its area, say 40, then the quantity passing through No. 2 will be $40 \times 3 = 120$. The relative velocities must then be $\frac{40}{40} = 1$ and $\frac{120}{72} = 1\cdot\dot{6}$. The relative pressures will be

For No. 1 airway $26 \times 1^3 = 26$, (substituting o for s).

" " 2 " $36 \times 1\cdot\dot{6}^3 = 166\cdot\dot{6}$ do.

Therefore $\frac{166\cdot\dot{6}}{26} = 6\cdot41$ times as much friction in No. 2 as in No. 1 for 3 times the quantity of air.

Question 112.—Given 10,000 cubic feet of air per minute through an airway 10 feet by 8, with a pressure of 10 lbs. per square foot, what is the length of the airway?

By the formula $s = \frac{pa}{kv^2}$, $s = \frac{10 \times 80}{\cdot0000000217 \times 125^2} = 2{,}359{,}446$ square feet of rubbing surface, and since the perimeter is 36, the length of the airway is $\frac{2{,}359{,}446}{36} = 65{,}540$ feet.

Question 113.—What precautions should be adopted where candles and safety lamps are used in different parts of the same mine?

The practice of having "mixed lights" in a mine is one to be condemned, but if some extraordinary event made it necessary for a temporary purpose, the points to be observed are to see that no return air after having passed through the workings lighted by safety lamps should be allowed to pass through the workings lighted by candles or open lights. Each district should be ventilated by means of a separate intake and return airway. Proper precautions should be taken to prevent persons using candles from entering that part of the mine lighted by safety lamps.

By General Rule 8 of the Coal Mines Act, 1887—"When it is necessary to work coal in any part of a ventilating district with safety lamps, it shall not be allowable to work the coal with naked lights in another part of the same ventilating district situated between the place where such lamps are being used and the return airway."

Question 114.—If 1 cubic foot of gas should explode, how many cubic feet of flame would it make?

The law of the expansion of gases is that every 460 volumes of gas measured at 0° F., and at a pressure of 30 inches, expand to 461 volumes for each degree of temperature on Fahrenheit's scale the gas is raised.

The proportion of oxygen to nitrogen in the air is about $\frac{1}{5}$th. As oxygen combines with twice its volume of hydrogen, $\frac{1}{2}$ a cubic foot of oxygen would be required to unite with a cubic foot of hydrogen, necessitating about $2\frac{1}{2}$ cubic feet of air. There would then be a mixture of $3\frac{1}{2}$ cubic feet. Taking the heat of the explosive mixture of gas and air to be equal to that of 2,348° F., every 460 volumes become by explosion equal to $2{,}348 + 460 = 2{,}808$. $\therefore$ as $460 : 2{,}808 :: 3\frac{1}{2} : 21{\cdot}3$ cubic feet; that is, 1 cubic foot of gas becomes 21·3 cubic feet of flame.

Question 115.—At what velocities do the Davy (without shield), Stephenson and ordinary Clanny lamps become unsafe?

The Davy explodes in an inflammable mixture of gas and air when the current moves at a velocity of 6 feet per second, the Stephenson and ordinary Clanny lamps at 9 feet per second. If these lamps are to be used it must be in currents considerably below this.

Question 116.—Supposing a 40 horse-power fan gives 120,000 cubic feet per minute, what quantity of air will a fan of 32 horse-power give?

As $\sqrt[3]{40} : \sqrt[3]{32} :: 120{,}000 : 111{,}398$ cubic feet of air per minute or $\sqrt[3]{\left(\frac{32}{40}\right)} \times 120{,}000 = 111{,}398$ cubic feet.

Question 117.—If 10,000 cubic feet of air pass per minute along an aircourse 7 feet square, how much will pass through the aircourse if it be reduced to 4 feet by 3, the power remaining the same?

Here the formula $q = \sqrt[3]{\frac{u}{ks}} \times a$ may be used, but as no length of airway is stated, substitute o for s, and the relative values will not be affected if k also, which is common to both airways, be omitted. Then $q = \sqrt[3]{\frac{u}{o}} \times a$. No actual value is assigned to u, so for convenience make it a multiple of o, say 28, and the proportion then is

$$\text{As } \sqrt[3]{\frac{28}{28}} \times 49 : \sqrt[3]{\frac{28}{14}} \times 12 :: 10{,}000, \text{ or}$$

$$\text{As } 49 : \sqrt[3]{2} \times 12 :: 10{,}000 = \frac{10{,}000 \times 1{\cdot}25992 \times 12}{49} = 3{,}085{\cdot}5 \text{ cubic feet}$$

per minute for the smaller aircourse.

Question 118.—Supposing the workings of a colliery to be ventilated by a Guibal fan $21\frac{1}{4}$ feet in diameter, going at 40 revolutions per minute, how many cubic feet would the fan produce? The air is to pass through 4 separate airways, 2 of them being 6 feet by 5 feet and 1,000 fathoms in length, and 2 are 8 feet by 5 feet and 1,200 fathoms in length: what would be the height of the water-gauge in each airway, and also in the main airway at the bottom of the downcast pit, which is 12 feet × 6 feet, and 60 fathoms in length?

The theoretical water-gauge (close to the fan) that a Guibal fan $21\frac{1}{4}$ feet in diameter, going at 40 revolutions per minute would produce, is ·902 inch (the height of barometer and thermometer slightly affect the water-gauge).

Thus, by the formula $h = \frac{v^2}{64·4}$, where v = speed of the tips of vanes in feet per second, and h = the height of column necessary to create such velocity in a falling body.

$$\therefore\ h = \frac{\left(21·25 \times 3·1416 \times \frac{40}{60}\right)^2}{64·4}$$

$h = 30·7$, and therefore the water-gauge would be $\frac{30·7 \times 2}{68} = ·902$ inch.

The depth and size of the shafts are not stated, and even if they were it could only be told approximately what proportion of the ventilating pressure will be spent in forcing the air through them. Assume it to be $\frac{1}{4}$th of the total pressure; for overcoming the friction due to the shafts, then ·902 — ·226 = ·676 as the water-gauge due to the underground workings between the two shaft bottoms; and as the airways must all leave the main intake at 60 fathoms from the downcast, and all come into the return at the bottom of the upcast, the water-gauge due to each of the 4 split airways will be the same.

The relative pressures for overcoming the friction are as follow:—

	Area in feet.	Rubbing surface in square feet.
Main Intake	72	12,960
No. 1 airway	30	132,000
,, 2 ,,	30	132,000
,, 3 ,,	40	187,200
,, 4 ,,	40	187,200

Assuming now that any quantity, say 50,000 cubic feet, are passed along the main airway, the relative quantities going into the four airways, which must get the total among them will be found by the formula $R = \sqrt{\left(\frac{a^3}{s}\right)}$, thus,—

$$\text{For No. 1 airway } R = \sqrt{\frac{30^3}{132,000}} = ·45226$$

$$\text{,, ,, 2 ,, ,, } = \sqrt{\frac{30^3}{132,000}} = ·45226$$

$$\text{,, ,, 3 ,, ,, } = \sqrt{\frac{40^3}{187,200}} = ·5847$$

$$\text{,, ,, 4 ,, ,, } = \sqrt{\frac{40^3}{187,200}} = ·5847$$

Total 2·07392

For a total of 50,000 cubic feet circulating, the proportion of volumes going into each airway must be,

For No. 1	As 2·07392 :	·45226 : :	50,000 :	10,904
,, 2	,, 2·07392 :	·45226 : :	50,000 :	10,904
,, 3	,, 2·07392 :	·5847 : :	50,000 :	14,096
,, 4	,, 2·07392 :	·5847 : :	50,000 :	14,096

By the formula $p = \frac{ksv^2}{a}$ now proceed to find the relative pressures for the

main intake and any one of the four airways due to the above quantities, since p is the same in all four.

then for the main intake $p = \dfrac{\cdot 0000000217 \times 12{,}960 \times 694 \cdot 4^2}{72} = 1 \cdot 8837$ lb.

„ No. 1 airway $p = \dfrac{\cdot 0000000217 \times 132{,}000 \times 363 \cdot 5^2}{30} = 12 \cdot 614$ lbs.

so that the total pressure for the quantity assumed to pass would be 12·614 + 1·8837 = 14·4977 lbs. per square foot.

But there is actually only a water-gauge of ·676 inch or ·676 × 5·2 = 3·5152 lbs. per square foot pressure due to the underground workings between the shaft bottoms. The proportion of the pressures, however, will hold good between the main intake and the airways so that the actual pressures will be,

For the 4 airways As 14·4977 : 12·614 : : 3·5152 : 3·0584 lbs.
„ main intake As 14·4977 : 1·8837 : : 3·5152 : ·4568 lb.

and these pressures as indicated by the water-gauge would be $\dfrac{3 \cdot 0584}{5 \cdot 2} = \cdot 588$ inch and $\dfrac{\cdot 4568}{5 \cdot 2} = \cdot 088$ inch, that is the water-gauge due to friction in the main airway is ·088 inch and that due to each of the four split airways is the same, viz., ·588 inch.

Now proceed to find the actual quantity of air circulating in the mine.

By the formula $v = \sqrt{\dfrac{pa}{ks}}$ and substituting values for the main airway $v = \sqrt{\dfrac{\cdot 4568 \times 72}{\cdot 0000000217 \times 12{,}960}} = 341 \cdot 9$ feet per minute, therefore the quantity actually circulating is 341·9 × 72 = 24,616 cubic feet per minute.

Or say, as the water-gauge to produce 50,000 cubic feet per minute would be $\dfrac{14 \cdot 4977}{5 \cdot 2} = 2 \cdot 788$ inches, the quantity that would circulate with a water-gauge of ·676 inch is, As $\sqrt{2 \cdot 788} : \sqrt{\cdot 676} :: 50{,}000 : 24{,}620$ cubic feet, which is almost the same result as before, the difference being due to loss in dropping decimals.

Question 119.—What are the chief points to bear in mind in the adoption of a fan which is to supersede a furnace that produces 30,000 cubic feet of air per minute with a water-gauge at the pit bottom of ·3 inch? Give the difference in water-gauge when the fan produces 60,000 cubic feet of air per minute, the circumstances of the mine remaining unaltered.

The chief points to be borne in mind in choosing a fan to supersede a furnace are that a certain water-gauge, whether caused by a fan or by any other machine, only circulates a certain quantity of air through the mine.

That at a given speed a fan can never get more than a certain constant water-gauge, but that if the fan be not properly proportioned, or if it be too small for the airways, the air will be throttled at the fan which will then get less than the water-gauge due to its speed. In choosing a fan one should be decided on that will do the work required with as small a consumption of fuel as possible and for that reason it should be driven by a compound engine if a new engine has to be purchased for the purpose. In answer to the latter part of the question, if the quantity of air be doubled the water-gauge is increased $2^2 = 4$ times, and it would therefore read ·3 × 4 = 1·2 inch.

Question 120.—If 20,000 cubic feet of air are produced in an airway 500 fathoms in length, 8 feet in breadth, and 4 feet in height, how many feet would be

produced if the air was split into three divisions, the first airway being as the above, the second 600 fathoms in length, 9 feet in breadth, and 5 feet in height, the third 800 fathoms in length, 10 feet in breadth, and 6 feet in height, the power being the same?

Use the formula $u = ks\left(\frac{q}{a}\right)^3$ or ksv^3 and for the airway passing 20,000 cubic feet at a velocity of $\frac{20,000}{32} = 625$ feet a minute $u = \cdot0000000217 \times 72,000 \times 625^3 = 381,444\cdot7$ units, or $\frac{381,444\cdot7}{33,000} = 11\cdot5589$ horse-power.

Then, for the power to remain the same for the 3 airways,

		Area in feet.	Rubbing surface in square feet.
For the 1st	8 feet × 4 feet × 3,000 feet long	32	72,000
,, 2nd	9 feet × 5 feet × 3,600 ,,	45	100,800
,, 3rd	10 feet × 6 feet × 4,800 ,,	60	153,600
	Total	137	326,400

Then by the formula $q = \sqrt[3]{\frac{u}{ks}} \times a$; $\sqrt[3]{\frac{381,444\cdot7}{\cdot0000000217 \times 326,400}} \times 137 = 51,736$ cubic feet as the quantity which would circulate with the same power.

Question 121.—If in a heading 7 feet 6 inches by 6 feet 8 inches the air travels 40 yards in 12 seconds, what would be the quantity of air passing per minute? If the water-gauge was 2·5 inches, what would be the horse-power?

Here $7\frac{1}{2} \times 6\frac{2}{3} = \frac{15}{2} \times \frac{20}{3} = \frac{300}{6} = 50$ feet area of airway. 40 yards = 120 feet, and if the air travels that distance in 12 seconds, its velocity must be as 12 : 60 :: 120 : 600 feet per minute, and the quantity passing is 600 × 50 = 30,000 cubic feet per minute. With a 2·5-inch water-gauge the horse-power of ventilation is $\frac{30,000 \times 5\cdot2 \times 2\cdot5}{33,000} = 11\cdot82$.

Question 122.—If with a ventilating fan running at 65 revolutions per minute 1·02 inch of water-gauge is produced, what will be the water-gauge if the fan speed be increased to 96 revolutions per minute?

The water-gauge varies as the square of the quantity and also, since the quantity is proportional to the speed of the fan, as the square of the revolutions $\therefore \left(\frac{96}{65}\right)^2 \times 1\cdot02 = 2\cdot22$ inches.

Question 123.—If with a ventilating fan running at $93\frac{1}{2}$ revolutions per minute 1·3 inch of water-gauge is produced, what will be the water-gauge if the fan speed be altered to 82 revolutions per minute?

As the water-gauge varies as the square of the revolutions, then as $93\cdot5^2 : 82^2 :: 1\cdot3$ or $\left(\frac{82}{93\cdot5}\right)^2 \times 1\cdot3 = 1$ inch of water-gauge.

Question 124.—If a ventilating fan is running at 40 revolutions per minute with 1·5 inch of water-gauge, and it be altered so that the water-gauge reads 2·6 inches, what will be the fan speed?

The quantity of air passing varies as the square root of the water-gauge, and as the quantity is in direct proportion to the fan speed, the latter also varies as the square root of the water-gauge $\therefore \sqrt{\frac{2{\cdot}6}{1{\cdot}5}} \times 40 = 52{\cdot}67$ revolutions.

Question 125.—If a ventilating fan is running at 80 revolutions per minute with 3·75 inches of water-gauge, and the speed be altered so that the water-gauge reads 1·82 inch, what will be the fan speed?

Here, As $\sqrt{3{\cdot}75} : \sqrt{1{\cdot}82} :: 80$ or $\sqrt{\frac{1{\cdot}82}{3{\cdot}75}} \times 80 = 55{\cdot}73$ revolutions.

Question 126.—In an explosion of gas at 70° F., what would be the difference of expansion in volume, the combustion taking place at 9,564°?

A gas expands $\frac{1}{460}$th of its volume at 0° F. for each degree it is raised above that point under a constant pressure.

Therefore any 460 volumes at 0° become $460 + 70 = 530$ volumes at 70°, and at 9,564° the volume would be $460 + 9{,}564 = 10{,}024$. In other words, the relative volumes occupied by a gas at the respective temperatures of 70° F. and 9,564° F. will be represented by the figures 530 and 10,024, so that the difference of expansion in volume is as 530 : 10,024 or as 1 : 18·9, that is, every cubic foot of the explosive mixture at 70° becomes 18·9 cubic feet at 9,564°.

Question 127.—How would you ventilate a mine giving off CH_4 and CO_2 freely, and what kind of airways would you adopt and what proportion should they be to one another?

I should make no distinction in ventilating a mine giving off CH_4 or light carburetted hydrogen gas at one portion and CO_2 or carbonic acid gas at another, except not allowing the air from the one portion to return so as to mix with the other. By the first general Rule of the Mines Act, 1887, we are bound to provide an adequate amount of ventilation in every mine to dilute the noxious gases so as to render them harmless. Both CH_4 and CO_2 are noxious gases, and the means of diluting them the same, viz., by providing and coursing round the districts of the mine such quantities of pure air as to ensure the rendering harmless of these gases. Air containing 3 or 4 per cent. of CO_2 is unfit to be breathed, and therefore we must be sure that a district giving off that gas has air in the proportion of 100 to 3 of the quantity of CO_2 given off, or about 33 to 1, and as also CH_4, when mixed with the air in the proportion of 1 in 30, will show a "cap" on the flame of a lamp, we shall require 30 parts of air in any district giving off CH_4 to every 1 part of CH_4 so given off. I do not mean to say that it is sufficient merely to dilute these gases so that the one may be just in a breathable state and the other be just beyond the point of its showing a cap; the figures are given merely to show that the relative quantity for this purpose is nearly the same. Therefore the proportion of air required in the different districts of a mine, taken in consideration simply of these gases, will be practically the same, but other considerations, such as the number of workmen employed in each, &c., may affect the relative quantities we should send into

each. I would then, ventilate any mine by a judicious arrangement of splits, and the kind of airways would be governed to some extent by the thickness of the seam worked. Theoretically, the most effectual shape of airway is the circular; the circular, however, is not practicable in our underground roadways, but a square one, which is the next best form, frequently is, and where practicable, I should adopt it, and where impracticable I should be careful to make the airways of a large sectional area, and if limited as to height, of a width to ensure the sectional area being sufficient, but I should prefer the square form. The proportions of airways for districts giving off CH_4 and CO_2, as already shown, apart from other considerations, may be the same.

CHAPTER XII.

SURVEYING AND PLANNING.

General Use of Working Plans—Chaining Distances—Construction of the Spirit Level—Method of Taking Levels—Ordnance Bench Marks—The Adjustments of the Spirit Level—Forms of Levelling Book—Mr. Wells's Hints on Levelling Operations—The Miner's Dial—Davis's Improved Hedley Dial—The Hoffman Joint—Method of Needle Surveying—Vernier or "Fast" Needle Surveying—Reducing Angles to an Original Base Line—Declination, Diurnal Fluctuation, and Dip of the Needle—Construction of the Transit Theodolite—Method of Using the Theodolite Underground—The Adjustments of the Theodolite—The Protractor and its Use—The Parallel Ruler and its Use—Scales—Survey Book—Paper for Colliery Plans—Meridianal Lines on Plans—Separate Plan of each Seam's Workings—Desirability of Placing Full Information on Colliery Plans—Plotting the Surveys—"Tieing" Surveys—Plotting Sections—Colouring Colliery Plans—Computation of Areas and Produce of Coal from them—Setting Out Railway Curves—Making Geological Sections—Louis's Improved Davis's Clinometer—Practical Questions and Answers.

A VERY important item in colliery operations is the making and maintaining, in compliance with the Mines Act, 1887, accurate plans of the workings in the different seams.

Plans are indispensable as a guide to the mining engineer or colliery manager in directing the workings, designing the best means of ventilation, guarding against old workings containing water or gas, keeping well within and leaving a proper barrier against the boundaries defined in the lease of the colliery, and for giving notice to the proprietors of railways, canals, &c., when the workings have approached within a specified distance of their surface property. In some instances the royalty rents are chargeable on the amount of coal worked; such amount being calculated from the areas as proved by survey and plotted on the working plans.

Surveying instruments are divided into three classes:—1. Instruments for measuring distances. 2. Instruments for measuring angles. 3. Instruments for plotting the survey.

Those ordinarily used for Class No. 1 are the chain or tape, the spirit level, and levelling staves. Those for measuring angles, which are applicable to mine surveys, are the miner's dial and the theodolite. Under the head of No. 3, the different forms of protractor, the parallel ruler, the T-square, the set-square, and scales, will be considered.

Gunter's Chain is that which is almost universally adopted for measuring distances. It is 66 feet or 4 poles in length, and is divided into 100 links joined together by rings. The length of each link together with the rings connecting it with the next is $\frac{66 \times 12}{100} = 7{\cdot}92$ inches. To every tenth link are attached pieces of brass of different shapes for readily counting the distances which may be fractional parts of a chain.

With the chain, on the surface, 10 or 11 arrows also are used, the latter number being preferable, but they are not often used in underground measuring as they

will not stick in the floor, and the custom is to mark the end of a chain with chalk on the floor or the rails. Care is required to measure straight between the two marks set up, which on the surface are usually rods, and underground must be lights.

Horizontal distances only are shown on the plan, and these will not be the actual distances measured where the ground rises or falls. On the surface, approximate horizontal measurement may be obtained by holding one end of the chain up, so as to keep it in a horizontal position, and plumbing from the handle to the ground ; but where the ground is very steep, it is impossible to hold out a whole chain-length in this way, and it has to be done by using a part of the chain, say 40, 30, or 20 links at a time, according to the fall of the ground. It is, however, difficult to tell when the chain is being held horizontally, and it is much better instead of adopting this method, to measure the distances along the surface of the ground, and by taking the angles of elevation or depression over the several inclined parts of the line with the instrument used for measuring the angles, the correct horizontal distances may be computed. The underground measuring admits of no other method. Tables prepared from calculations, may be

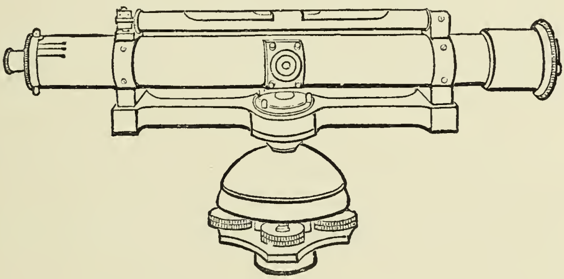


Fig. 345.—Dumpy Level with Hoffman Joint.

obtained, showing this correction for every 100 links for any angle whatever. For measuring the depths of shafts, or in making plans whose areas are required in square feet, or it may be for plans of surface buildings or other purpose, a chain 100 feet in length, divided into links a foot long, is to be preferred. Chains made of steel are lighter to use than those made of iron.

The tape may be made of any length, but those mostly in use are 33, 50, 66, or 100 feet long, and there are different ways of dividing them. The most generally useful one is divided into feet and inches on one side and links on the other, so that it can be used to measure either. In surveying it is used to measure long offsets from the chain, the lengths of buildings, &c., on the surface, where its use is a necessity in addition to the chain, but it is seldom required in underground surveying.

The Spirit-Level is an instrument used in measuring the vertical distances between different places. It consists of a glass tube which is not quite cylindrical in form, but having its diameter largest in the middle and decreasing slightly and with great regularity from the middle to the ends. The tube is nearly but not quite filled with spirits of wine, thus leaving in it a bubble of air, which rises to the highest part of the tube and which, when the instrument is adjusted, has the two ends of the bubble equally distant from the middle. A scale is generally scratched on the glass to guide the operator in adjusting the instrument. This spirit-level is fixed to the telescope by a joint at one end and a capstan-headed screw at the other so as to raise or depress it for adjustment.

In the Dumpy level, which is the most common form used, a cross-level is placed upon the telescope at right angles to the principal level, which enables the instrument to be fixed more readily, or a circular level is placed immediately under the telescope.

Fig. 345 shows Messrs. Davis & Son's Dumpy level, with Hoffman patent joint. It has achromatic lenses, and all parts are of gun-metal. Two eye-pieces are provided with the instrument, and a tripod of polished mahogany.

In the construction of a level not fitted with Hoffman joint the telescope is attached to a horizontal bar, and sometimes this bar carries a compass-box, which is convenient for taking bearings. Beneath this bar is a conical axis passing through the upper of two parallel plates and terminating in a ball supported in a socket. The two parallel plates are connected together by means of this ball and socket, and are set firm by four milled-headed screws which turn in sockets fixed to the lower plate, while their heads press against the under side of the upper plate and so serve to set the instrument up truly level. Below the lower parallel plate is a female screw adapted to the staff-head, which is connected by brass joints with three legs, which shut together in one round staff or may be opened out to stand firmly on the ground, however uneven it is. The telescope has a focussing arrangement, and near the eye-piece is a diaphragm carrying cross hairs, by means of which the observer reads the staff.

The operation of levelling is conducted as follows :—

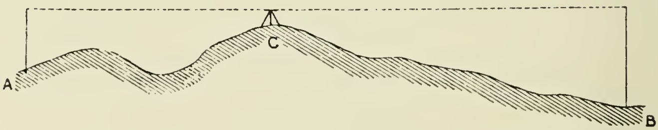


Fig. 346.—Illustrating the Operation of Levelling.

Let A and B be two points (Fig. 346), and the difference of level between them is required to be known. Place the instrument at C and adjust it in a truly horizontal position. Then a levelling staff, divided in feet and decimals (to 2 places), being placed at A, read the height of the staff there and remove it to B. The telescope being turned round, read the height of the staff at B, and if now one reading be deducted from the other it gives the difference of level between A and B. The staff at A is called the back-station, and the reading taken there is called the back-sight, whilst the staff at B is called the fore-station, and the reading there is called the fore-sight. If the back-sight is greater than the fore-sight the difference of level is called a rise ; if the back-sight is less than the fore-sight, the difference of level is called a fall. If in the above case the back-sight read 6·42 feet and the fore-sight 10·17 feet, there would be a fall of 10·17 — 6·42 = 3·75 feet, which, in other words, would mean that B was 3·75 feet below the level of A. When from the nature of the ground it is not possible to see from one point or position of the instrument the two extremes, a series of simple levels like the one indicated above must be made, the fore-station at each plant of the instrument being made the back-station at the next, and from the combination of all the results is obtained the required difference of level between the desired points.

When it is required not only to find the difference of level between two distant points, but to make observations that will enable a section to be drawn, showing the undulations of the ground along some specified route, the stations must be chosen so that they are at the commencement of each change in the inclination of the ground, the distances between each station must be care-

fully measured, and these measurements must be reduced to horizontal measurements when plotting the section.

A number of sights may be taken with the instrument from the same position if the ground be very undulating and it is desired to note every change of inclination; in that case, it is usual to call all but the fore and back stations intermediate stations, and book their staff-readings as intermediate sights. It is usual also to assume that the starting point is so many feet (frequently 100) above datum line, unless some well defined datum line, such as would be obtained from an Ordnance bench mark, is used; the reason for assuming the starting point to be a certain number of feet above datum line being the convenience both of keeping the book and of plotting the levelling.

Ordnance bench marks are the broad arrows cut on stone walls, window-cills, coping-stones, or other prominent and convenient places by the ordnance surveyors. The ordnance plan-sheets of any locality have similar arrow-marks on them at the places shown on the plans where the marks have been cut, and, in addition, a number printed distinctly at the arrow, thus B.M. 562·25, which indicates that that particular arrow is 562·25 feet above mean sea-level at Liverpool. These marks serve as a record by means of which subsidence or elevation of land may be measured. The counties of Lancashire and Yorkshire, *e. g.*, are at present (1890) being re-surveyed by the Ordnance surveyors, and many changes in the surface level since the original survey of 1852 have been brought to light. At a point on the line between Warrington and Adlington, the surface is as much as 6·523 feet lower, while the bench mark in Wigan old church has sunk 5·825 feet. In the latter case the surveyors observed a subsidence of one foot in a year. In the neighbourhood of Barnsley, Doncaster, and Rotherham, the ground has sunk, over an area of about 100 square miles, in some cases as much as 5 feet. Of the original bench marks on the principal lines in the two counties, 47 per cent. have been destroyed or have disappeared, 11 per cent. have been moved more than one-tenth of a foot, and only 42 per cent. remain undisturbed, that is, differ less than one-tenth of a foot from the published levels. These changes are no doubt the result of mining operations.

In taking levels of the surface in South Wales, we have frequently observed a difference of a foot, or rather more, in the relative levels of bench marks at short distances apart, proving subsidence of the land in that district.

The level is a delicately made instrument, unable to stand rough usage, and even with care in its use is easily deranged. Before using in the field or the mine the instrument should be thoroughly examined and its adjustment tested.

The adjustments are for parallax, collimation, and the perpendicularity of the telescope-axis to the vertical axis round which the instrument moves.

Parallax is shown to exist when by moving the eye about on looking through the telescope, the cross-hairs in the diaphragm change their position and are flittering and undefined. To correct this error, adjust the eye-piece by drawing out or in the moveable eye-piece tube, till the cross-hairs appear clear and well defined. Then move the internal tube, by means of the milled-headed focus-screw, until the distant object to be sighted and the intersection of the wires, are clearly and sharply defined. It may not always be sufficient to set the eye-glass first and then the object-glass, it may be necessary to adjust the eye-piece again. This adjustment is made continually throughout the time of taking levels, so far as the object-glass is concerned, as it will have to be altered at every change of distance at which the staff is observed.

The adjustment for collimation becomes necessary owing to the diaphragm carrying the cross-webbing getting deranged, the consequence of which is to cause every point bisected by the hairs to be either above or below the true level point.

To examine and correct the collimation; on a gently and uniformly sloping ground (Fig. 347), measure off a distance, A B, about 160 feet, and place a levelling-staff, A C and B D, at each end of this distance. Plant the instrument exactly half-way between the staves, and after levelling it, read off the fore- and back-sights.

Whether the collimation be out of adjustment or not, the difference in the readings obtained will be the *true* difference of level.

At E, about 12 feet from A C (or as near to it as it is possible to clearly distinguish the figures and obtain a reading of the staff), set up the instrument in line between the staves and take back- and fore-sights. In Fig. 347, J K is the horizontal line through the axis of the telescope. F G, F H, and F G_1, F H_1, represent the lines of collimation for the back- and fore-sights respectively, the two former if the cross hairs in the diaphragm are too high, and the two latter if they are too low.

The true difference of level of the ground at the two staves or L = K B — J A (1); but K B = B H, ± K H, and J A = A G, ± J G. Substitute these

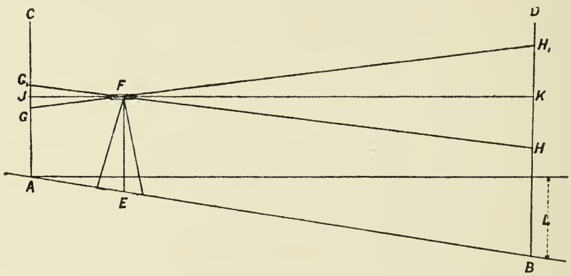


Fig. 347.—Collimating the Level.

values in equation 1, then $L = BH \pm KH - AG \mp JG$ (2), and by similar triangles $\frac{JG}{JF} = \frac{KH}{FK} \therefore JG = KH\,\frac{JF}{FK}$. Instead of this last expression take $KH\,\frac{AE}{EB}$, the ratio being the same, and A E and E B are the distances as actually measured.

Substitute this value of J G in equation 2 and $L = BH \pm KH - AG \mp KH\,\frac{AE}{EB}$.

By transposing and reducing

$$KH = \frac{L - BH + AG}{\pm 1 \mp \frac{AE}{EB}}$$

Having thus found K H, the diaphragm must be moved by the capstan-headed screws provided for the purpose until the reading on the staff, B D, is B H ± K H = B K; then the line of collimation will be horizontal.

If B H — A G is $\left\{\begin{matrix}\text{greater}\\ \text{less}\end{matrix}\right\}$ than L, use the $\left\{\begin{matrix}\text{lower}\\ \text{upper}\end{matrix}\right\}$ sign in the above formula. To take an example, let A E = 12; E B = 120; L, or the true difference of level, 1·53; A G 3·21, and B H 5·15.

$$\text{Then } KH = \frac{1{\cdot}53 - 5{\cdot}15 + 3{\cdot}21}{-1 + \frac{12}{120}} = \frac{-{\cdot}41}{-{\cdot}9} = {\cdot}4\dot{5}$$

Now move the diaphragm till the reading of B D is 5·15 − ·45 = 4·70, when A C will read 3·17, and the instrument is properly collimated.

Another way to test the collimation is to bring the telescope over two of the parallel plate-screws and the air-bubble to the centre of its run by moving the screws.

Set up a staff very carefully and take a reading of it. Give the telescope half a revolution on its own axis, before doing which it will be necessary to withdraw the screws which hold it in place in the clips, and as the focussing screw would otherwise prevent its rotation, remove it by means of the screws which connect the plate carrying it to the telescope. When the telescope is half turned round in the clips observe the staff again, which should read the same as before if the diaphragm carrying the cross hairs is in its true position. If not, move the capstan-headed screws of the diaphragm in the telescope until the reading of the staff is mid-way between the two previous readings. Turn the telescope to its original position, and if the reading still differs the operation must be repeated by correcting half the error by means of the diaphragm capstan-headed screws. It may be necessary to repeat the operation a few times before the adjustment is perfect, but on completion, the readings of the staff obtained by the telescope in its two positions must be exactly alike.

To set the axis of the telescope at right-angles to the vertical axis round which the instrument turns, which is the final adjustment to describe, bring the telescope over two of the parallel plate-screws and give them motion, till the air-bubble settles in the centre of its run. Turn the instrument half round upon the vertical axis so that the telescope is pointing in the opposite direction, and note if the bubble settles at the same point as before; if not, half the error must be corrected by turning the bubble-tube capstan-headed screws placed for the purpose over the telescope, and the other half by turning the two parallel plate-screws over which the telescope is placed. Next turn the telescope a quarter round, till it is at right-angles to its previous position and over the other pair of parallel plate-screws. Give motion to these screws until the bubble settles in the centre of its run, and turn the telescope half round on its vertical axis so that the contrary ends of the telescope may be over the same two screws, and if the bubble does not settle in the centre of its run, half the error must be corrected by turning the bubble-tube capstan-headed screws over the telescope, and the other half by turning the parallel plate-screws. The operation may have to be repeated, till, after a few trials, the bubble maintains exactly the same position in the centre of its run, while the telescope is turned slowly, and with pauses in the motion, all round upon the vertical axis. This adjustment, which should be made before collimating, is then complete, and the vertical axis of the instrument made truly vertical.

On being now set up and levelled by using the two pairs of parallel plate-screws, so as to bring the air-bubble to the centre of its run, whatever direction the telescope is turned in, the line of collimation moves round in a horizontal plane, unless the instrument itself has defects in its construction.

With the instrument in this carefully adjusted state, the operator may with confidence commence the necessary observations, the accuracy of which as they are taken will depend only on his own skill in manipulating the instrument and keeping his levelling-book.

There are many methods of keeping a levelling-book, and three different examples are here submitted.

LEVELS OF PROPOSED BRANCH RAILWAY AT ——— COLLIERY, FEBRUARY 10TH, 1886.

Distance in Links.	Sights. Back.	Sights. Inter.	Sights. Fore.	Rise.	Fall.	Reduced Rise.	Remarks.
0	8·59					100·00	On — Railway 150 feet below the Red Lion Inn.
100		7·27		1·32		101·32	
156		10·15			2 88	98·44	
193		8·76		1·39		99·83	
235		9·58			·82	99·01	
280	12·43		6·04	3·54		102·55	
345		9·78		2·65		105·20	
460		7·56		2·22		107·42	
524		6·82		·74		108·16	
596		8·45			1·63	106·53	
620							Crosses hedge.
694		9·52			1·07	105·46	
753		10·89			1·37	104·09	
806	7·56		11·53		·64	103·45	
920		8·21			·65	102·80	
985		9·40			1·19	101·61	
1,050		7·79		1·61		103·22	
1,124		9·65			1·86	101·36	
1,243		11·33			1·68	99·68	
1,297		12·94			1·61	98·07	
1,365		13·84			·90	97·17	
1,500	6·45		14·00		·16	97·01	
1,582		8·42			1·97	95·04	
1,644		9·81			1·39	93·65	
1,700		11·32			1·51	92·14	
1,800			12·47		1·15	90·99	
1,900	7·84		9·42		1·58	89·41	
	42·87		53·46 42·87	13·47	24·06 13·47		
	Difference ...		10·59		10·59		

and 100 − 10·59 = 89·41, the reduced rise.

The following is the same levelling in another form :—

Distance in Links.	Sights. Back.	Sights. Fore.	Height of Instrument.	Reduced Rise.	Remarks.
				100·00	On —— Railway, 150 feet below the Red Lion Inn.
0	8·59		108·59		
100		7·27		101·32	
156		10·15		98·44	
193		8·76		99·83	
235		9·58		99·01	
280	12·43	6·04	114·98	102·55	
65		9·78		105·20	
180		7·56		107·42	
244		6·82		108·16	
316		8·45		106·53	
414		9·52		105·46	At 340 crosses hedge.
473		10·89		104·09	
526	7·56	11·53	111·01	103·45	
114		8·21		102·80	
179		9·40		101·61	
244		7·79		103·22	
318		9·65		101·36	
437		11·33		99·68	
491		12·94		98·07	
559		13·84		97·17	
694	6·45	14·00	103·46	97·01	
82		8·42		95·04	
144		9·81		93·65	
200		11·32		92·14	
300	7·84	12·47	98·83	90·99	
100		9·42		89·41	
1,900	42·87	53·46			
		42·87			
Difference being a fall of ...		10·59			

Starting point above datum ... 100 feet.
Deduct fall between start and finish 10·59

Finishing point above datum ... 89·41

Another form, requiring only four columns, is as follows:—

Distance Links.	Level Readings.	Reduced Levels.	Remarks.
		108·59	
0	8·59	100·00	On —— Railway, 150 feet below the Red Lion Inn.
100	7·27	101·32	
156	10·15	98·44	
193	8·76	99·83	
235	9·58	99·01	
280	6·04	102·55	
	12·43	114·98	
65	9·78	105·20	
180	7·56	107·42	
244	6·82	108·16	
316	8·45	106·53	
414	9·52	105·46	At 340 crosses hedge.
473	10·89	104·09	
526	11·53	103·45	
	7·56	111·01	
114	8·21	102·80	
179	9·40	101·61	
244	7·79	103·22	
318	9·65	101·36	
437	11·33	99·68	
491	12·94	98·07	
559	13·84	97·17	
694	14·00	97·01	
	6·45	103·46	
82	8·42	95·04	
144	9·81	93·65	Starting point above datum ... ... 100 feet.
200	11·32	92·14	
300	12·47	90·99	Deduct fall between start and finish ... 10·59
	7·84	98·83	Finishing point above datum ... ... 89·41
100	9·42	89·41	

1,900	53·46	Total Fore-sights.
	42·87	Total Back-sights.
Difference being a fall of ...	10·59	

On comparing the three forms, it will be observed that the first requires eight columns as compared with six in the second, and four in the last. That the method of filling in the distances is continuously from the starting to the finishing point in the first, whilst in the other two the distances are only continuous for one "plant" of the instrument, and an addition made of these at the end. An advantage claimed for the first form is that it checks every level filled in when added up at the bottom of the page, whilst there is no such check on the intermediate levels in the other methods. Against this it may be fairly claimed for the second and third forms that there is less figuring required, and that they are more simple than the first. It will be observed that the Reduced Levels and Remarks are the same in all three cases; that in the first form the first row of intermediate figures have to be subtracted from the figures under the head of back-sight, or the latter are subtracted from the former, the result being placed as a rise if the intermediate sight is less than the back, and as a fall if more. The next figures in the Inter. column are either deducted from those previously placed in the Inter. column, or else the previous Inter. column figures are subtracted from them, and the result placed as a rise or fall. These rises or falls are added to or subtracted from the figures in the Reduced column all the way down the page. At the bottom of the page, or sooner termination of the levelling, an addition is made of the Back, Fore, Rise and Fall columns, as shown, and the difference between the Back and Fore must agree with the difference between the Rise and Fall shown in the addition, and this difference must also agree with the difference of the Reduced Level at the finish and at the commencement. In the second form, taking the starting point as being 100 feet above the datum line, and the reading for the back-sight being 8·59, it is obvious that the height of the instrument itself must be $100 + 8{\cdot}59 = 108{\cdot}59$ feet above datum, and placing these figures in a column to itself, called Height of Instrument, every other reading of the staff placed on the chosen stations during the first "plant" are entered as fore-sights, and subtracted from the figures in the Height of Instrument column, the result being the Reduced Level. On fixing the instrument again, we read for the back-sight 12·43, which must be added to the figures 102·55 in the Reduced Level column, and the result placed in the Height of Instrument column. All other readings whilst the instrument remains in its second position are booked as fore-sights, and these are each subtracted from the figures last placed in the Height of Instrument column. For the sake of clearness, the figures that have to be added at the bottom of the page are underlined, because all that are in the Distance and Fore columns are not to be added together, but only those indicated by the underlining which form a part of those columns. In practice this underlining is unnecessary in the levelling book, because the eye easily rests on the figures to be added together, as they are in a line with the figures in the Back and Height of Instrument columns. Besides the underlined figures in the Fore and Distance columns, the Back column figures must be added at the foot of the page, and the method afterwards explains itself. If the levelling is to be continued further, the totals at the foot of one page are carried forward to the next.

The third form is simply a modification of the second, whereby two of the columns there used are dispensed with. Instead of having two columns for back- and fore-sights, all the level readings are entered in one column, and the first entered after each "plant" of the instrument is a back-sight, and the last the fore-sight. A line is drawn across the first three columns after taking the fore-sight and removing the instrument. These lines serve to distinguish the proper figures to add together at the foot of each page. Thus, only the figures in the Level Readings column immediately over the lines ruled are added together for the total fore-sights, and only those immediately under the lines are added together for the total back-sights, the rows between these extremes not forming a part of

either addition. The Height of Instrument column is dispensed with, and the figures really forming the height of the instrument are entered in the Reduced Level column. These are not to be plotted, but are merely used as a basis each time for ascertaining the levels of other stations which have to be plotted. There is little fear of confusing these figures with those in the Reduced columns, which have to be plotted, as the line drawn immediately over them, together with the blank space in the Distance column alongside, sufficiently distinguishes them.

The plotting of the levelling just given will be shown later on, after plotting instruments have been explained.

A very interesting pamphlet on "Hints on Levelling Operations, as applied to the reading of distances by the law of perspective, and the saving thereby of chainmen in a level survey," by W. H. Wells, C.E., was published in 1879 by E. & F. N. Spon, from which the following remarks are drawn.

The image of the staff, or any portion of it, seen in the telescope of a level will diminish as the distance the staff is moved from the telescope increases, according to the laws of perspective.

If when the staff is held, say, 100 feet from the telescope, the portion of the image of the staff contained within the space A B, Fig. 348 (being the horizontal

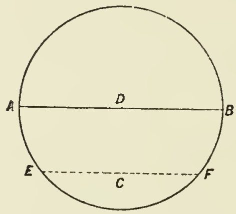


Fig. 348.—Shifting Arrangement in the Diaphragm of a Telescope.

cross hair), and C (being the lower edge of the diaphragm), be 1·50 foot, a datum is obtained from which can be ascertained any distance that the staff is afterwards moved, by reading the portion of its image enclosed within the vertical space D C. For instance, if the staff be now moved, and, on directing the telescope to it, it is found that the portion of the staff image contained within the space D C is 2·10; the distance to the staff will be found by a simple proportion sum, thus:—As 1·50 : 2·10 :: 100 : 140; that is, the staff in its new position is 140 feet distant from the telescope.

Instead of using the lower edge of the circular diaphragm, a more accurate outline of a portion of the staff image is obtained by fixing a second horizontal hair either near the bottom or top of the diaphragm, as shown dotted at E F.

If this second hair is a fixture in the diaphragm, the surveyor must ascertain his own datum at a distance of 100 feet, by carefully measuring out that distance on the ground, the staff being placed at one extremity and the telescope at the other, and then reading the portion of the staff image enclosed between the lines A B and E F. A note of this reading is made in the survey book, and all further levelling operations may be proceeded with without using the chain. All the surveyor has to do after reading the staff in the ordinary way is to read and enter in a proper column in his survey book the portion of the staff image contained between the lines A B and E F. The distances can be worked out after the day's operations are finished, and this is done by a series of proportion sums.

The form of book must necessarily be altered to suit the particular method. The following would appear to be quite clear, although it is open to the objection of having many columns.

Datum distance, reading, say, 1·50 of the staff image = 100 feet.

	Distance Readings.				Level Readings.						
	Reading of 2nd cross hair.	Back.	Fore.	Distance in feet worked out.	Back.	Inter.	Fore.	Rise.	Fall.	Reduced Rise.	Remarks.
A	10·32	1·73	......	115·33	8·59	......	......	......	......	100·00	....
B	...8·01	·74	......	49·33	......	7·27	......	1·32	......	101·32	....
C	10·34	·19	......	12·66	......	10·15	......	......	2·88	98·44	....
	....	......	......		......	......	......	......	......	....	....
D	...8·93	......	·17	11·33	......	8·76	......	1·39	......	99·83	....
E	10·17	......	·59	39·33	......	9·58	......	......	·82	99·01	....
F	...7·08	......	1·04	69·33	......	......	6·04	3·54	......	102·55	....
	....	......	......		......	......		......	......	....	....
F	15·20	2·77	......	184·67	12·43	......	......	......	......	....	....
G	11·91	2·13	......	142·00	......	9·78	......	2·65	......	105·20	....
H	...8·55	·99	......	66·00	......	7·56	......	2·22	......	107·42	....
J	...7·18	·36	......	24·00	......	6·82	......	·74	......	108·16	....
	....	......	......		......	......	......	......	......	....	....
K	...8·80	......	·35	23·33	......	8·45	......	......	1·63	106·53	....
L	10·84	......	1·32	88·00	......	9·52	......	......	1·07	105·46	....
M	12·80	......	1·91	127·33	......	10·89	......	......	1·37	104·09	....
N	13·96	......	2·43	162·00	......	......	11·53	......	·64	103·45	....

In this form, a line is drawn between the distances at C and J, to show the position of the instrument, and these are ruled in the survey book, whilst the operations are going on ; the distances may afterwards be filled in. A line is also drawn under the Level Readings Fore column at F, as well as in the Distance column, and this distinguishes between the position of the instrument and the last sight taken by it each time of fixing.

The example above shown is the first two "plants" of the level in the Levelling given previously in other forms of keeping the level book, and taking distances in the ordinary way.

It will be noticed that the reading of the second cross hair at F, after moving the instrument, is 15·20, and with a 14-foot staff the instrument could not have

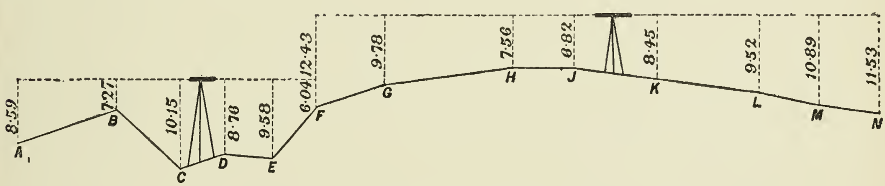


Fig. 349.—Staff Readings obtained from a Levelling.

been used in this way for distance reading, unless it had been placed at a lower level.

There are, no doubt, times when shorter sights must necessarily be taken as a consequence of working by this system, but there is a much greater advantage obtained from having no chainage to do, and all the distances read are horizontal ones. Where great accuracy is desired, the distances may be chained and checked by the staff distance readings.

Fig. 349 shows the position of the instrument when the preceding readings were taken.

It is plain that the distances, as worked out in the level book, will be those between the position of the instrument and the different stations on which the

staff was held on either side of it, and this must be borne in mind when plotting. If the distance between B and C was required, then $49{\cdot}33 - 12{\cdot}66 = 36{\cdot}67$ feet. Similarly the distance between any other two stations may be obtained.

An objection to having the second cross hair fixed in the diaphragm at any convenient distance from the usual horizontal cross hair is the fact that a series of proportion sums must be worked out before the distances are obtained. But this objection may be removed if the instrument maker fixes to the instrument a properly arranged diaphragm, in which the second cross hair can be moved and regulated by the surveyor himself, by means of a thumb-screw placed either above or below the diaphragm of the instrument.

Having this shifting arrangement, the surveyor may bring 1 foot of the staff image in the space between the two cross hairs at 100 feet distance, or any other portion convenient to himself. If he make the former arrangement, there will be no proportional sum to find the distances, or only such as can be made mentally in a moment. For instance, if the space between the cross hairs read 2·15 after such an adjustment were made, the distance from the staff will be 215 feet; if ·65, it will be 65 feet.

If by means of the regulator two or more whole feet of the staff image is contained between the two horizontal hairs at 100 feet distance, more accurate readings will be obtained.

Another advantage of this regulator is in the facility it affords for reading the distance to the other side of a river or other large obstruction, when the staff figures are beyond the limits of vision. In this case, the regulator is adjusted until either the whole staff, or a portion whose length is known, placed on the opposite side of the obstruction, is enclosed between the cross hairs.

Without further touching the regulator, a staff is now held on the same side of the obstruction as that on which the instrument is, but 100 feet from it, and the figures enclosed within the horizontal hairs then noted. A proportion sum then gives the width of the obstruction. For instance, if the regulator be adjusted to include the whole of a 14-foot staff between the horizontal hairs, when the staff is placed on the opposite bank of a river and the reading of the distance between the horizontal hairs (the regulator not having been moved) on a staff 100 feet distant from the instrument on the same side of the river is 1·45 foot; the distance across to the opposite side is as $1{\cdot}45 : 14{\cdot}00 :: 100 : 965{\cdot}52$ feet.

If in addition to the regulator for adjusting the space between the two horizontal hairs, a scale of equal parts be fixed outside the telescope, and a point conveniently attached to the adjusting arrangement be made to move along the scale, the amount of the space may be shown on the scale. When the two hairs coincide and there is no space between them, the pointer on the scale would indicate zero. Any other position of the second cross hair would be read on the scale of equal parts. With this arrangement no staff would be required on the other side of the river. The telescope may be directed to any suitable object such as a tree or a house, and the space between the horizontal hairs carefully adjusted until the object selected is exactly enclosed therein, and the reading on the scale of equal parts noted. The instrument is then moved backwards to a suitable distance, and from this new position the space between the horizontal hairs is again made to enclose the same object within it. The reading on the scale of equal parts is noted, and as the distance is increased the reading will be less than that first taken. The distance of the first position to the object is found by the following proportion sum. As the number of equal parts of the scale first read minus the number of equal parts of the scale next read is to the number of equal parts of scale at first observation so is the distance that the telescope was moved to the distance required. For instance, if at the first point of observation 8 equal parts were noted as the space between the horizontal hairs enclosing the object, and at the second point of observation 120 feet back from the first

point of observation 7 parts were noted. Then as 8 — 7 : 8 :: 120 : 960 feet, the distance required.

This last arrangement of the regulator with scale is more suitable for range finding than ordinary surveying operations.

Mr. Wells has suggested to Messrs. Elliott Brothers, of St. Martin's Lane, London, opticians, a contrivance which may be inserted in any levelling telescope by boring a small hole in the tube just behind the diaphragm, which will give a vertical space between the horizontal hairs, and adjustable by the surveyor in the diaphragm of the telescope without interfering with existing cross hairs and a scale of equal parts attached thereto. The surveyor can obtain this at a small cost, and it will be so constructed that he can himself attach it to any make of levelling telescope.

The most common instrument used for measuring angles underground is the Miner's Dial, also called the Circumferentor or Compass. It is fixed on three

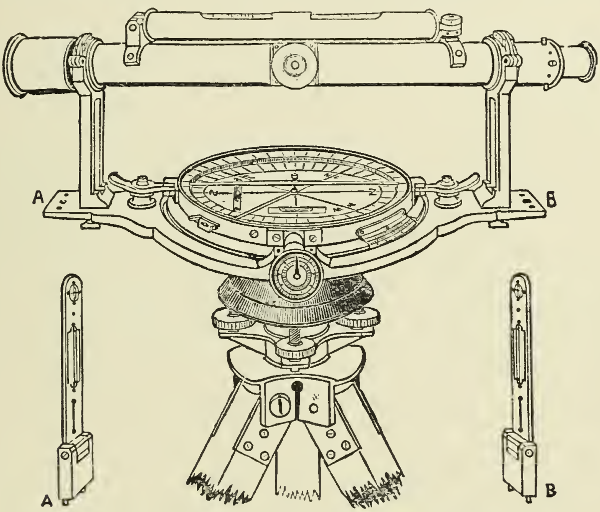


Fig. 350.—Davis's Improved Hedley Dial with Hoffman Joint.

strong legs, which should have joints to unscrew in the middle or at other divisions to suit the height of the seam. It has a magnetic needle turning on an agate centre, and is hung on a very fine hard-pointed pin, so that it may swing freely, and the north end is usually distinguished by a short pin placed through it. It has one or two graduated circles showing degrees and half degrees, and a pair of sights fitted with hairs in an exact line with the centre of the instrument. The best kind of dials have also verniers attached to them which read to minutes (the $\frac{1}{60}$th of a degree), a tightening screw for clamping the lower plate by means of a collar, and a slow-motion-screw working a rack and pinion for giving a slow motion to the sights, by means of which angles are read without the use of the needle, or by what is sometimes called "fast-needle" angles. Some dials have a ball-and-socket joint at the neck, others have parallel plates, and more recently the Hoffman joint has been invented and applied to others. Two spirit levels are placed in the compass box at right angles to each other, to ensure the needle being level when taking an observation. All modern instruments have a vertical arc, or an equivalent arrangement, placed on them for reading the angles of elevation and depression, but in the old form of dial this was wanting.

Fig. 350 shows Davis's improved Hedley Dial. The improvement in this dial

consists of an arrangement by which the bearings are taken simultaneously with loose needle and vernier, the latter *automatically* checking the former, thus any error arising from incorrect reading or from any local attraction is detected.

A telescope or upright sights may be used, being interchangeable on the dial, as shown at A B in the drawing. The vernier is placed on the outside circumference of the instrument, in which position it is easier read than when placed inside the compass box. When the telescope is substituted for the upright sights, it more nearly approaches the form of a theodolite, and in consequence gives a result to the surveyor using it closely approximating to the superior instrument, whilst its weight and size give it an advantage over that instrument for most of the surveys required underground. The figure arrangement on the dial is designed to inspire the surveyor with confidence in the work of surveying as it progresses. Those marking the divisions in the compass box circle are formed so that the readings correspond with those of the vernier circle. Both circles are marked from left to right for this purpose.

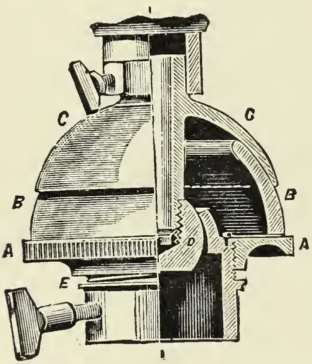


Fig. 351.—Hoffman Joint for Dials with Upright Sights.

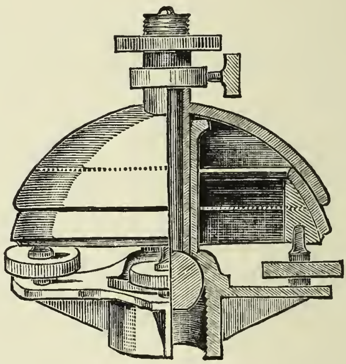


Fig. 352.—Hoffman Joint for Levels or Dials with Telescopes.

In place of a side arc for taking vertical angles as with the old form of Hedley, the improved instrument has a circular box $1\frac{3}{4}$ inches in diameter, the pointer on which traverses a dial-plate divided into 90°. It is very neat and compact, and presents no obstacle to the surveyor when manipulating the screws.

Fig. 350 shows the improved Hedley Dial having a Hoffman patent joint. This joint, as specially designed for Miner's Dials without telescopes, is shown at Fig. 351, and the following advantages over the ball and socket are claimed for it.

(1) The plumb line is suspended from D, the actual centre of the dial, which cannot be achieved with the ball and socket.

(2) The rubbing surface is some ten times greater, and therefore the joint is far more rigid.

(3) The joint is manipulated with greater ease and despatch, a slight turn of the milled flange, A, A, from right to left liberates the two concentric balls, B and D, the dial is then levelled up, and a slight turn of the flange from left to right secures the joint.

(4) Only one hand is required to manipulate the joint.

(5) The total height of the improved joint is 3 in., the ordinary ball and socket $3\frac{5}{8}$ in.

(6) The length of the centre is $2\frac{1}{8}$ in., that of the ball and socket is barely $1\frac{1}{2}$ in., thus the dial reverses with greater accuracy.

While possessing many and important advantages, the joint is no heavier than the ball and socket.

Fig. 352 shows the Hoffman patent joint for levels or dials having telescopes with four screws for fine adjustment and for clamping joint.

The method of using the needle for measuring angles underground consists in placing the instrument in the roadway leading from the shaft or other starting point, having first removed to a distance of 5 yards on either side all iron, which is known to deflect the needle, and having levelled the instrument, the sights of the compass are turned to a light at the starting point, the needle having first been liberated by a spring placed for the purpose. When settled, the needle will point to the magnetic north and the observer has to read and note the number of degrees the sights are lying from magnetic north, and in which quadrant those degrees are. The number of the sight beginning with 1 is entered in the survey book, the magnetic bearing and also the distance in links as measured from the shaft or other starting point to the dial, as well as the angle of inclination (if any) are also noted. The sights are then directed to a forward light, and the reading of horizontal and vertical angles together with the chain distance between the dial and the forward station booked. The dial is then lifted, carried forward, plumbed under the forward station, and a light being held at the station from which the instrument has just been removed, it is sighted through the dial, when the angle reading observed should correspond with the reading last booked; if not, some error has crept in which must be eliminated before proceeding further. If it correspond, the sights of the dial are directed to the forward light and the reading of the needle and any angle of inclination booked, the measurement from the dial to the last sighted station is then made, and noted, the instrument being again moved to the forward station. The process is here repeated and so throughout the length of road it is desired to survey. If a branch road leading from that which has now been surveyed, has also to be included in the survey, the surveyor, after completing the main road survey, must come back to where it branches off, and having made a note in the survey book at the time of advancing along the main road, such as "mark left opposite branch road," he now makes another note to identify the new starting point, thus say, "from 350 in 11," which means that the next sight following this remark was taken from 350 links in the eleventh set or sight going in. The survey may now be continued along this branch road, and afterwards in the same way along any number of other roads leading out of this, or other branches from the main road.

Now supposing it is required to survey from the shaft into the workings with a Hedley dial of ordinary construction, by angles not measured with the needle, but by the vernier, so as to avoid much labour in rail lifting.

First take out the screw which tightly holds the vernier plate to the bottom plate of the dial and prevents the possibility of the upper and lower plates having a separate motion during an ordinary needle survey. This screw will not be replaced till the completion of the survey. Set up the dial at a distance from the shaft, the farther from it the better, so long as a light at the pit bottom can be seen. Great care should be taken that at this first point of setting up the dial, which call A, the rails are taken up, and everything likely to attract the needle of the compass removed to a safe distance.

The instrument having been levelled, the needle is freed, and allowed to steady; after which the sights are turned so that the north end of the needle exactly coincides with the *zero* point of the lower plate of the dial, while at the same time the *zero* point of the vernier plate corresponds with that of the lower plate. The bottom plate is then clamped, by means of the collar tightening screw, the position of which is just above the ball-and-socket joint. The clamping screw of the vernier plate (the position of which is immediately underneath the vernier) is then slackened, and by means of the slow-motion screw (the position of which is underneath the dial plates, and opposite the clamping screw of the vernier plate) the sights and vernier plate are together moved until a light held by an assistant

at the centre of the shaft is bisected *through the bottom slit* of the sights. The vernier plate clamping screw is then tightened, the angle read by means of the vernier to 3 minutes, or to 1 minute according to the accuracy of the instrument used, and the reading booked. The vernier plate clamping screw is then slackened, and the slow-motion screw used for bisecting *through the upper slit* of the sights a light which has been taken forward by an assistant along the road to the next station B. The vernier plate clamping screw having been tightened, the angle is read by means of the vernier and booked. Whilst these angles have been taken in the way indicated, the needle has remained on the zero point of the lower plate. The dial is now plumbed, a mark left to look back to, and the needle "locked," after which the instrument is removed to station B, plumbed underneath the mark previously sighted there and set up level. The lower clamping screw must now be slackened, but that of the vernier plate remains tightened, and a light held at A, is bisected *through the bottom slit* of the sights ; the lower clamping screw is then tightened. Having proceeded thus far, as a matter of prudence, the angle indicated by the vernier should be again read, and if it does not agree with the angle last booked some slip must have occurred in carrying the instrument or otherwise, and it will be necessary to repeat the operations at A. Suppose the angle indicated by the vernier to correspond with that last booked; if the needle be now freed it will settle over the *zero* point of the lower plate, unless it is subject to some attraction. The vernier plate clamping screw is now slackened, and by means of the slow-motion screw a light held by an assistant at a forward station, C, is bisected *through the upper slit* of the sights; the vernier plate clamping screw tightened and the angle read and booked. The instrument is then removed to C, and the same process gone through as at B, and so on throughout the survey. By continually sighting the back station through the lower slit, and the forward one through the upper, the vernier is kept at the leading end of the dial throughout the survey.

It is desirable that the survey should be constantly checked as it proceeds, and for this purpose, after every few "sets" the rails should be taken up, and as much care exercised to remove all iron, as there was at the first station of the survey. If at any point where this has been done, after the back-sight has been taken, the needle on being freed, instead of lying on the zero point of the lower plate, should settle a degree or two from it; it is a proof that either a mistake has been made in the survey or that some attraction exists, which, perhaps, may not be easily detected. If the survey be gone over again up to this point, and with the same result, one would be justified in deciding that it was owing to attraction, and not to incorrect surveying, that the needle did not settle on the zero point. It is necessary to say this, because, with all the care that can be taken, at times there is some influence over the needle which cannot be discovered, and the amount of that influence is indicated by the position of the needle with regard to the zero point of the lower plate.

It may be wiser in some instances, instead of surveying in from the shaft to the face to work from the face outwards. In others, a disused road may be taken advantage of as a good starting point. It would be wise to do so, for instance, where the first set from the shaft is a short one, or where iron pipes are laid, or the shaft itself contains a great deal of iron—pumps, &c.

In this method of surveying, besides the advantage of the constant check kept on the survey as it proceeds (by means of the needle), there is a further advantage in all the angles taken being magnetic bearings. They are as readily plotted as are the "sets" of an ordinary survey with the needle, and are as easily converted into northings, southings, eastings and westings. In adopting it, the angles should be written in the book continuously from 0° to 360°, thus an angle which if read by the needle would be south would be booked 180° by "fast needle" as it is called, and N. 50° W. by the needle would be booked 310°.

Some surveyors adopt this method of booking their bearings when taken by the needle.

It is a very good practice to take the angles of a survey from true north in preference to magnetic north, as the latter varies continually. Another good practice is to have three sets of legs with lamps to fit on them and to be interchangeable with the dial.

It is the practice of some surveyors when working with "fast needle," instead of taking the angles continuously from magnetic or true north, to take the angle that one part of the road forms with another, irrespective of the magnetic or other bearing of the first part. But this plan is not desirable because by taking the first sight as a base line, all the other angles have to be submitted to calculation, in order to render their plotting easier. Or, as an alternative to calculation, a great waste of time arises in the plotting from having to shift the protractor for every set. In old makes of dials, however, no other course can be pursued, owing to the incomplete appliances on the dials themselves. The method of reducing all the angles of a survey to the original base line is as follows:—

If the angle is less than 180° the difference must be subtracted from the previous angle. If it be more than 180° the excess must be added to the preceding angle. It should be stated, that if in following out this rule the angle as thus reduced should exceed 360°, the excess should be taken as the reduced angle.

Supposing the following angles to have been taken in a survey. (1) base line, (2) $89°20'$, (3) $110°52'$, (4) $192°35'$, (5) $211°27'$, the reduced angles would be (2) $89°20'$ (this of course being an angle from the base line remains unaltered), (3) $89°20' - (180° - 110°52') = 20°12'$, (4) $20°12' + (192°35' - 180°) = 32°47'$, (5) $32°47' + (211°27' - 180°) = 64°14'$.

Too much reliance should not be placed on dial surveys, the horizontal angles of which have been taken with the needle. The best form of Miner's Dial approaches to that of a theodolite, and the angle readings obtained are read by means of a vernier. Being more portable than the theodolite, it may be very usefully employed for many purposes underground, but in cases where extreme accuracy is required surveyors use the more perfect instrument in the mine, and rely almost altogether on it for surface work.

It is well-known that the magnetic north differs at the present time (1890) from true astronomical or geographical north. The angle formed between them is called the declination of the needle, and is continually changing. The declination may form an angle either east or west of true north; at the beginning of 1886 the magnetic needle had a westerly declination of $17°54'$ at Greenwich, but is diminishing about $8'$ annually. In 1660 there was no declination, and the time will probably come again when there will be none. The declination is not the same in all parts of the world. In travelling west of Greenwich it increases. Two magnetic needles have seldom exactly the same variation, so that if a needle survey were made of the underground workings, and the surface were surveyed with another needle, an error would arise in connecting the two if proper allowance were not made for the difference of variation in the needles. The needle is subject to periodical variations, the most important being a diurnal fluctuation from east to west. The north end of the needle reaches its most westerly position at about 2 p.m., and its most easterly position at night or early morning, the difference between its extreme positions amounting to 10 or 12 minutes or more in summer, but to much less in winter, and is irregular at times between the extreme seasons. The average position of the needle in making its diurnal movement is attained about 10 a.m., and again about 6 p.m. The fluctuation is at its minimum near the equator and increases in advancing northwards from it. The needle is acted on by magnetic storms, which may seriously deflect it from its ordinary position.

What is called the dip of the needle is its direction as compared with a vertical line. In order that a needle may assume a horizontal position after being magnetised, it is first carefully balanced before magnetization and is then slightly weighted at its southern extremity. The mean magnetic dip at Greenwich in the year 1886 was $67°27'$ and was diminishing annually at the rate of $1'24''$.

The modern form of theodolite has a telescope which can be moved round the entire circle in the vertical plane, and is called a transit theodolite.

Fig. 353 shows Messrs. Davis & Son's Transit Theodolite, and Fig. 354 that of Hoskold's Miner's Transit Theodolite, as supplied by Messrs. John Davis & Son, All Saints Works, Derby.

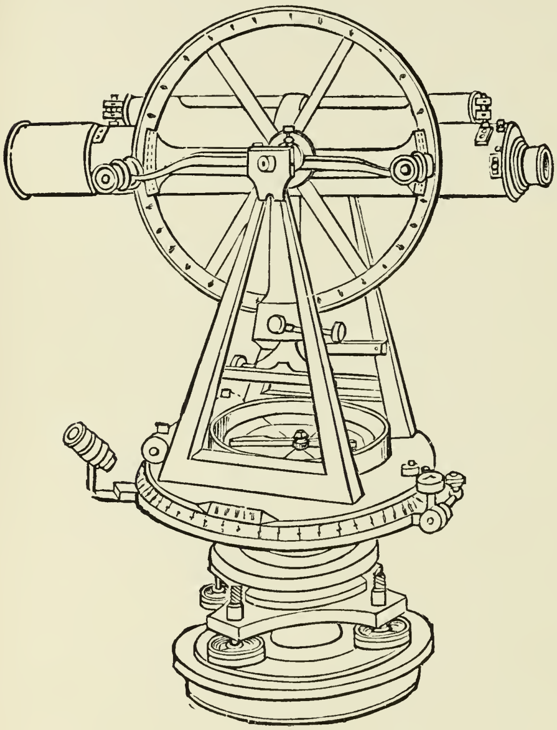


Fig. 353.—Davis's Transit Theodolite.

In Fig. 353, the telescope, with a spirit level fixed on it, rests on upright supports, which are of such a height above the horizontal circles as to admit of the telescope turning right round on its axis. It is provided with a vertical circle, and by means of verniers and microscopes the angles of elevation or depression are read. The horizontal limb is composed of two circular plates, which fit accurately one upon the other. The lower one is chamfered and graduated at every half or every third of a degree. The upper is called the vernier plate, and has portions of its edge chamfered off, so as to form, with the chamfered edge of the lower plate, continued portions of the same surface, and these chamfered portions of the upper plate are graduated to form the verniers by which the limb is subdivided to single minutes. Usually there are two such verniers placed 180° apart. By means of clamping screws the upper plate may have a motion independent of the lower plate or it may move with it.

There is a clamping screw fixed to the vernier plate for the purpose of keeping the two plates together when tightened, or of allowing the upper plate to move whilst the bottom one is fixed. A tangent or slow-motion screw gives the upper plate a slow motion after the clamping screw is fastened. Similarly, a clamping screw tightens the collar below the bottom plate, and a slow-motion screw is placed for moving the whole limb through a small space so as to adjust it more perfectly after tightening the collar. Two spirit levels are placed upon the horizontal limb at right angles to each other and a compass is sometimes placed upon it in the centre and between the supports for the vertical limb. As however, this only allows of a small compass, the more modern plan is to fix a magnetic needle in an oblong shaped box, and this trough compass is sometimes fixed on the telescope on the side opposite the main spirit level and sometimes it is made to slide under

the lower plate. This arrangement allows of the use of a larger and more reliable needle. Two parallel plates with four milled-headed screws similar to those on the spirit level are placed below the lower plate as a means of adjusting the levels accurately before making an observation with the instrument. The vertical limb is divided upon one side every 30 or 20 minutes and two verniers are placed so as to read the vertical angles to single minutes. The vertical limb has a clamping screw and a slow-motion screw, the former on being tightened holds the telescope at the desired inclination, and for more carefully adjusting it in taking an observation, the slow-motion screw moves it through a small space. The instrument is screwed on to the top of a tripod in a manner similar to the spirit level.

The theodolite, like the miners' dial, and the spirit level, may have Hoffman's patent joint attached to it for the more speedy setting up and plumbing.

A good arrangement for underground work is to have three sets of legs for the theodolite and to make these with joints that are all interchangeable and will accommodate themselves to any height. A lamp should rest on these when taking the sights, to be afterwards lifted off and by the substitution of bayonet catches for the ordinary screw the theodolite instead of being screwed on.to the tripod head may be dropped into position, to be as easily taken off again after the necessary observation has been made and carried to the forward set of legs, whilst a lamp is placed on the set from which the theodolite has just been lifted.

The method of using the theodolite underground is similar to that described for fast needle surveying.

The instrument after being levelled, and the needle liberated, is clamped by the lower clamping screw while the needle rests on the zero point of the compass box, and the upper limb is securely held to the lower by its clamping screw with the verniers reading respectively 360° and 180°. The vernier plate clamping screw is then slackened which allows the upper plate with, of course, the telescope and vertical limb to move freely round in a horizontal direction whilst the lower limb remains securely clamped. To allow of the telescope being tilted to suit any inclination in the roadway, the clamping screw of the vertical limb must now be liberated. The telescope is then directed to the back sight, and when the light

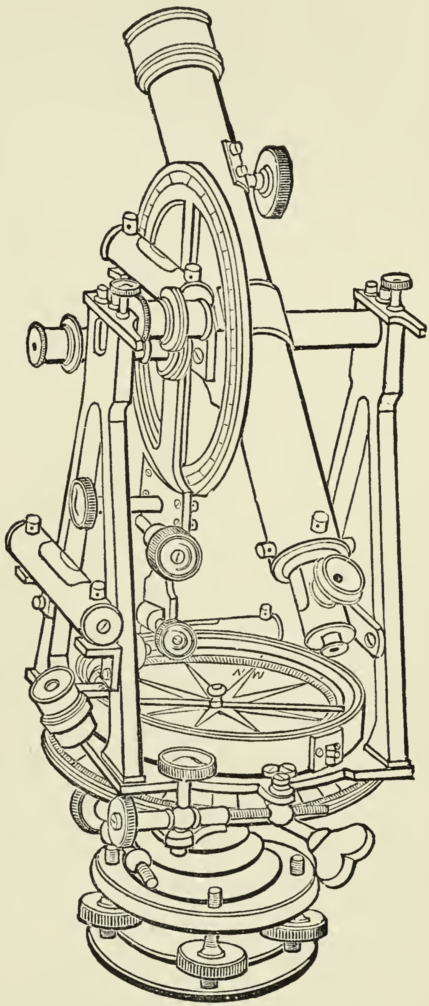


Fig. 354.—Hoskold's Miner's Transit Theodolite.

is bisected by the cross hairs in the diaphragm of the telescope or nearly so, the vernier plate and vertical limb clamping screws are fastened, and if the object has not been exactly bisected, the slow-motion screw of the vernier plate and that of the vertical limb bring the intersection of the cross hairs in the telescope accurately on the object. By means of a microscope placed for the purpose, both the horizontal and vertical angles may be read and booked; the latter read from 0° to 90° and the former from 0° to 360° and may be any intermediate figure. Having booked these readings the vernier plate and vertical limb clamping screws are slackened, the lower one still remaining fast and the telescope directed to the forward station when the vernier plate and vertical limb clamping screws are again fastened, and the horizontal and vertical angles booked.

Having first "locked" the needle the instrument should be plumbed so as to leave a mark under it and removed to the forward station, but much plumbing is saved by the use of three sets of legs. It is here fixed accurately over the mark previously sighted, and levelled, with the vernier plate clamping screw remaining fast in the position it occupied at the previous station, but the lower clamping screw is liberated. When the instrument has been set up, levelled, and plumbed over the forward station, the telescope is directed to the station previously occupied by the instrument and the lower clamping screw fastened. During these operations the vernier plate clamping screw has remained tight, and it is well now to check the reading of the vernier, which at the commencement was set at 360°, to see that it corresponds with the angle last booked. Having done this, the vernier plate clamping screw should be liberated, the telescope turned over on its axis so as to look the opposite way to the back station, and while the lower clamping screw remains firm the telescope is directed to the next forward station, the vernier plate clamping screw is fastened and the angles read and booked. The instrument is then removed to the next forward station and the same process repeated there and so throughout the survey.

If at any stage, after the back sight has been taken, the needle is freed, it should on steadying point accurately to the zero point of the compass box.

The method of traversing on the surface is similar to that underground, but for extensive surveys, the principal points should be determined by a system of triangles proceeding from an accurately measured base of considerable length. The details are afterwards filled in, but it would occupy too much space to fully describe surface surveying here. It may be said in passing that in filling in the details, offsets are taken with a rod or tape from the traverse lines, usually at right angles to them to all the points required to be shown in the survey, such as houses, hedges, fences, the edges of streams, &c.

Before commencing observations with the theodolite, the following adjustments must be attended to:—for parallax, for collimation, and adjustment of the horizontal and vertical limbs.

Parallax has already been described for the level, and the remarks hold good for the theodolite.

In collimating the dumpy level, it is only necessary to test the horizontal hair, but in the theodolite it is essential that the point of intersection of the vertical and horizontal (or other arrangement) of the hairs should be accurately in position, and therefore both hairs must be tested and if necessary adjusted. First the accuracy of the horizontal hair will be shown by directing the telescope to a levelling staff after the instrument has been set up level, and obtaining a reading which corresponds with another taken when the telescope is reversed in the clips. If the readings differ, half the error must be corrected by turning two of a group of four capstan-headed screws near the eye-piece, which two give vertical motion to the diaphragm carrying the cross-hairs. The telescope may be again reversed on the clips and a reading taken. If there is a difference still between it and the one taken before reversing, half the error must be corrected as before, and this

may have to be repeated a few times before the readings are exactly alike. The vertical hair must next be tested. For this purpose bisect with the cross-hairs a distant well defined object and clamp the instrument firmly in that position. Then reverse the telescope in the clips and note if the vertical hair passes exactly through the same object. If not correct half the error by turning the other two of a group of four capstan-headed screws near the eye-piece which give horizontal motion to the diaphragm. Reverse the instrument in the clips and if the vertical hair passes through the same object the instrument is adjusted, but if not the operation must be repeated again and again.

To test the horizontal and vertical limbs, first set up the instrument and carefully level it by means of the small level carried in the upright and its companion at right angles to it. Tighten the lower clamping screw and free the upper. The vernier plate is then turned until the telescope is over two of the parallel plate screws, after which the telescope is turned over in the vertical plane until the air-bubble in the tube over it is in the centre of its run. In this position the vertical arc is set at zero by means of its adjusting and tangent screws. Now remove the screws which hold the large bubble-tube clips to the telescope and reverse the bubble-tube. If the air-bubble settles in the centre of its run no adjustment will be required, but if not correct half the error by the capstan-headed screws at either end of the bubble-tube and the other half by the parallel plate screws. Return the bubble-tube to its former position when the air-bubble should settle in the centre of its run. If not repeat the operation until it does so whichever way it is turned. The lower level in line with the telescope must be watched during these operations to see that as it is disturbed by the parallel plate screws in adjusting the main level it is brought truly level by means of its capstan-headed screws, so that the two levels on completion remain true in whichever position the bubble-tube is turned. Now turn the vernier plate a quarter round so that the telescope is over the other pair of parallel plate-screws, while the two small levels remain with their air-bubbles accurately in the centre of their run. Turn the telescope over in a vertical plane until the air-bubble in the tube over it is in the centre of its run. Set the vertical arc at zero by means of its adjusting and tangent screws. Remove the screws which hold the large bubble-tube clips to the telescope, if they were screwed home after the first operation, and reverse the bubble-tube. If the air-bubble does not settle in the centre of its run, proceed as before to correct half the error by means of the capstan-headed screws at either end of the bubble-tube and the other half by the parallel plate-screws. Return the bubble-tube to its former position when the air-bubble should settle in the centre of its run. If not, repeat the operation until it does so, whichever way it is turned. The lower level in line with the telescope must be watched during these operations, and as it is disturbed by the parallel plate-screws in adjusting the main level, it is brought truly level by means of its capstan-headed screws, so that the two levels on completing the adjustment remain true whichever way the bubble-tube is turned.

This adjustment may be more easily made without removing the bubble-tube from its ordinary position, by turning the vernier plate on its vertical axis till the telescope points first in one direction and then in the opposite over each pair of parallel plate-screws.

Now turn the vernier plate slowly round in a horizontal direction until it returns to the position it started from when the main air-bubble and the small one in line with it will remain in the centre of their run throughout the movement. If the other small level air-bubble at right-angles to the main one is disturbed during the motion, it must be adjusted by means of its capstan-headed screws, and the trial repeated until all three air-bubbles remain in the centre of their run during the revolution of the vernier plate.

The vertical arc is then perpendicular to the horizontal limb and the other adjustments being perfect the instrument is ready for use in the field or the mine.

Of the instruments used for plotting, the protractor is one of the chief. A very useful form for working out geometrical problems is the small 6-inch ivory or box-wood protractor usually supplied with a box of mathematical instruments. Besides the divisions of degrees round three of its edges, it has a scale of chords and other scales on it.

For plotting surveys the protractor is usually a complete circle of brass, the centre being marked in some definite manner and the circle divided into 360 degrees, there being in those of large size divisions to show 15 minutes or $\frac{1}{4}$ degrees on them. Another form of protractor is the semi-circular. This is divided into 180° and has a folding arm with a vernier reading to single minutes. The method of using it is to place its straight edge against a T-square, the paper

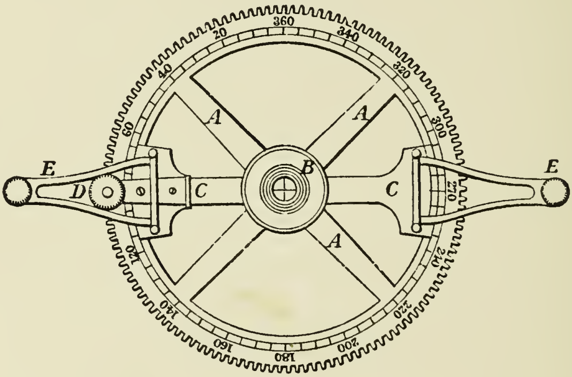


Fig. 355.—Davis's Circular Protractor.

for plotting on having first been secured to a drawing board, and the T-square being moved along the board in parallel lines, forms a meridian to work from. Any desired angle may then be marked from that meridian by the protractor whose straight edge is kept close against the T-square. The best form of protractor is the circular, having folding arms with prickers, and two verniers placed 180° apart, which read to single minutes. Fig. 355 shows this kind of instrument as made in brass, or electrum, by Messrs. John Davis & Son, Derby. A clamping screw secures the verniers at any desired reading, and a slow-motion screw is fixed on it for the more accurate adjustment to odd minutes. A magnifying glass should be held in the hand whilst adjusting the verniers. On their being placed in any required position each arm is lightly pressed on the paper, a puncture being left by the pricker under each arm, and these punctures should be numbered in accordance with the survey-book. A good plan is to mark only the punctures from one of the arms on first taking off the "sets," and then as a check to mark all the "sets" a second time, using the other arm to form a fresh set of punctures, each of which would be 180° from the first. The parallel ruler, on being placed so that its edge is in a line with the two punctures of any one set, should also be in a line with the centre mark over which the centre of the protractor was first placed, and if not, this indicates an error, to correct which the protractor must be placed on the paper again.

The best form of parallel ruler is made of brass or electrum, and runs on

milled wheels. It should be 2 or 3 feet long and sufficiently heavy to roll truly over the paper. Unless a parallel ruler is of the very best design and construction it is much better not to use it, but to rely more on a couple of large-sized set-squares which must be very true and accurate for getting parallel lines. The method of using these to obtain parallel lines will be understood from Fig. 356. Let it be required to draw a straight line parallel to A B. Place the edge of one set-square, C, against the line, and place the other set square, D, against the first; hold D firmly down and move C along the edge of D, and a parallel line will be obtained as shown in the dotted line; if lines are required at right angles to that parallel, it is only necessary to hold C and place D on it as shown in the dotted portion of the figure. Parallel lines may also for some purposes be obtained, as shown in Fig. 357, by sliding a set-square along the edge of a T-square.

Whether set-squares or parallel rulers are used for the plotting, care should be taken after the line is drawn to run the square or the parallel ruler back

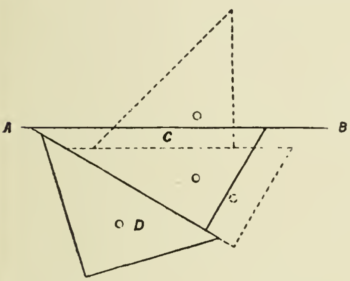


Fig. 356.—Drawing Parallel Lines with the Set-squares.

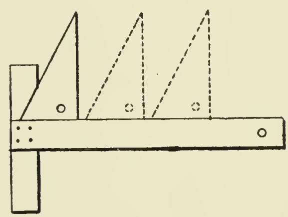


Fig. 357.—Drawing Parallel Lines with a T-square and Set-square.

to the punctures indicating the set, as a check that the line has been rightly placed.

Scales of equal parts are used for measuring straight lines and laying down distances. A very common scale for colliery plans is two chains to one inch, and the Mines Act, 1887, states that these plans shall not be kept on a smaller scale than that of the Ordnance Survey of 25 inches to the mile, or $\frac{1}{2500}$. A good form is to have a scale 2 feet long, of box-wood or ivory, and marked in links on one side of the scale and correspondingly in feet on the other. A small offset scale about 2 inches long, similarly marked, is useful for plotting the offsets of surface surveys.

The form of survey-book is a matter of some importance, as the booking of surveys should be methodical and clear, so that the survey could be re-plotted, if necessary, years afterwards. The practice of entering surveys carelessly, and trusting a good deal to memory in supplying deficiencies of booking, is much to be deprecated, as great importance may attach to a survey long after it has been made, and the survey-book, on being then referred to, should be as easy to read as at the date of survey. Instead of first writing at the beginning of the book and working down the first page, and then passing on to the top of the second page, the surveyor begins to fill in a survey at the end of the book and on the last line of the last page, writing upwards to the top and then passing to the bottom of the last page but one and writing up it. There are different methods of ruling a book, but the simplest appears to have one or two lines through the middle of each page, which represent the chain line as the survey

proceeds. The following is given as an example of an underground survey, showing the method of keeping the book and of plotting the survey:—

Face
2 20
198° 22′
(9)

5 6
197° 15′
(8)
From 1 26 in 5

Face
6 0
345° 58′
(7)

7 8
303° 18′
(6)

2 22
Road 1 26
297° 10′
(5)

5 0
265° 47′
(4)

4 26 End of Engine Plane
257° 19′
Fall (3) ∠ 10°

7 39
255° 49′
Fall (2) ∠ 9°

5 08
256° 33′
Fall (1) ∠ 10°

transit theodolite.
19° 30′ W. Commenced at No. 1 shaft, the survey being made with a 5-inch
1886. All horizontal angles are from true north, the magnetic declination being
plane and into the face of the workings on the Four feet seam. February 12th,
Survey made at the —— Colliery from the No. 1 shaft along the engine-

The number indicating the set is written on the central line and enclosed with a ring, whilst the vertical angle is written on a line with it, in the example given, showing at a glance that the engine plane dips from the shaft about 6 inches per yard. The horizontal angle is then booked, and this shows that the first part of the

road makes an angle with the true north of $256° 33'$, and the length of the part of the road which makes this angle is 508 links, and so on with the other parts of the road. Had a Miner's Dial been used and needle bearings taken, if its magnetic variation agreed with the theodolite needle, the horizontal angles would have read as follows:—(1) $360° - (256° 33' + 19° 30') = 83° 57'$, or N $83° 57'$ W; (2) $360° - (255° 49' + 19° 30') =$ N $84° 41'$ W; (3) $360° - (257° 19' + 19° 30')$ = N $83° 11'$ W; (4) $360° - (265° 47' + 19° 30') =$ N $74° 43'$ W; (5) $360° - (297° 10' + 19° 30') =$ N $43° 20'$ W; (6) $360° - (303° 18' + 19° 30') =$ N $37° 12'$ W; (7) $(345° 58' + 19° 30') - 360° =$ N $5° 28'$ E; (8) $(197° 15' + 19° 30') - 180° =$ S $36° 45'$ W; (9) $(198° 22' + 19° 30') - 180° =$ S $37° 52'$ W.

The paper used for permanent colliery plans is worthy of more attention than it receives; for after all possible care has been taken with it, it is subject to a certain amount of shrinkage. The paper should be well mounted and be properly seasoned before it is used. It is much better to show a true north line on these plans rather than a magnetic north, for the true north will not change, and either the instrument may be adjusted from time to time to read angles from the true north when making a survey, or the protractor may be placed by the true north point in such a way as to make allowance for the declination at the time of survey. A good plan is to have a number of faint lines dividing the plan into squares of, say, 10 acres area each; that would be 10 chains to each side of the square. One of the series of lines would represent a true north and south line, the other series east and west lines. These lines should be carefully put on with a long steel straight-edge, divided into inches and tenths. The squares will assist in any computation of quantities that may afterwards be required, and also any plotting that may be done either from a computation of the northings, southings, eastings, and westings of a survey, or in the ordinary way.

Having a plan-sheet of suitable size divided by lines as indicated, the surface surveys should be plotted on it, the boundary lines and pits inked in, and a distinctive marginal colour run round the different royalties which form the taking. The underground surveys of one seam should be afterwards plotted on this same sheet. If more than one seam is being worked it is better to have a separate plan-sheet for each seam rather than attempt to show the workings of two or three different seams on one plan as is sometimes done. To save plotting the surface survey again, a careful tracing may be made of the surface lines and transferred to one or more sheets. In this way there may be as many plan-sheets as there are seams of coal working, all having the same boundary lines and relative position of pits, but with the underground workings shown clearly for each seam.

There is not always sufficient care taken in making or extending colliery plans. The most complete not only show the underground workings and roads, but also, by distinctly coloured lines, the position of all faults, with the direction and amount of their throw; air-crossings, inclines, engine-planes, main doors, the position of engines and boilers; the direction of main and minor currents of air, and the flow along water-courses. Old workings and drowned wastes should have special colours on them, and in districts much disturbed by faults the plans should be supplemented by sections, the lines of which are indicated on the plans. Few plans, however, have all possible information on them. This may be excusable in mines in which the arrangements are in an experimental stage and subject to constant alteration; in a large number, however, which have arrangements developed and are not subject to much disturbance, these particulars are neglected. Again, contour lines should be shown, or the levels of the roadways marked in some clear manner, as these are always useful and may be most valuable hereafter. Contour lines are simply lines joining places of the same altitude. Thus it may be decided to show a contour line at a level of 50 feet above the pit bottom, another at 100

feet, another at 150 feet, and every other 50 feet, or contour lines may be marked at every change of 10 feet or other number according to circumstances. By levelling underground, these points of equal altitude in the different roads are ascertained, and afterwards connected on the plan by faint dotted lines. Or, if contour lines are not marked on the plan, the levels may be written neatly and clearly about the plan on all main roads. They show at a glance the probabilities of water taking certain directions; whether the coal has to be hauled up or down-hill to the shaft, and direct the manager's attention to parts of the road which probably may be improved. A record of this sort on one seam becomes a very valuable guide in directing the operations on another, the workings of which may follow over the same ground, and in the case of abandoned collieries, plans containing such information are of the utmost assistance to a neighbouring venture.

The Mines Act, 1887, renders it not only necessary to survey the workings and extend the plans in accordance therewith at least every 3 months, but also to show the general direction and rate of dip of the strata, together with a section of the strata sunk through, if the last be reasonably practicable.

To plot the survey by the protractor and parallel ruler, place the protractor as stated on one of the lines representing the true north and south meridian of the plan; if the angles of the survey were taken from the true north make use of the parallel meridian line which is most convenient. The protractor would be placed with its zero point on the north end of the line and with its centre on a continuation of the same line where it crosses one of the parallel lines at right angles to the meridian. A continuation of the same meridian line southwards will coincide with 180° on the protractor. The numbers of the sets should be then pricked off, each being twice marked, supposing a good protractor with folding arms to be used. A magnifying glass is held in one hand (the survey-book lying open on the plan), whilst with the other the vernier of the protractor is set at the angles, corresponding with those of the survey-book. The best plan is to mark all these off with only one of the prickers the first time, and then to go through them either backwards or forwards a second time and use the pricker on the opposite folding arm as before remarked. Should any error arise it will be discovered from the fact that a straight line between the two prick marks of the same set ought to cross through the centre point of the protractor which, in laying on the plan as stated, should be at the intersection of two of the lines referred to. The parallel ruler is then used and placed in a line with the two punctures representing the first set, and taken in a truly parallel course by means of its rollers across the paper to the point from which on the plan the first set was taken. A pencil line is carefully ruled of a reasonable length; by looking at the survey-book some judgment of this may be formed, but it is better to draw it long enough as the extra length not required may be rubbed out afterwards. The parallel ruler is now carefully moved back to the punctures at which it was first set, and if it corresponds with these the line will be truly drawn. If not, take the line out with india-rubber and repeat the operation. The operator must be careful not only to place the lines truly parallel with the set-marks but also not to reverse any of them and rule them on the plan in the opposite direction to which they should be. The scale may be now laid down to the line drawn and the length taken from the survey-book having first been subjected to the proper deduction for the vertical angle (if any) the horizontal length is marked on the line by a puncture, a pencil ring made round it, the number of the set written in pencil near the ring, and the excess of the line beyond the ring is taken out with india-rubber. The parallel ruler is then placed truly by the punctures representing the next set and brought in a carefully parallel line to the ring at the end of the line forming the first set. A pencil line is again ruled from this ring in the proper direction and the method of procedure cor-

responds with that described for the first set, and so on throughout the survey, taking care that if a remark "from —— in —— set" appears in the survey-book that the plotting proceed from the point indicated. The pencil used should be finely pointed and fairly hard—an H.B. is very suitable for the purpose. As these pencil lines represent the centre of the road (it being impossible to fix a surveying instrument right in the side of the road) it is customary, instead of inking in a single line on the plan representing the centre line, to rule two lines representing the sides of road, and these should be inked in at equal distances from the centre line which is shown in the plotting. Indian ink and a proper drawing pen are used for the purpose of inking in. Fig. 358 shows the plan of the survey before alluded to.

It is highly desirable that, wherever practicable, surveys should have proof of their accuracy by what is called "ties." A traverse survey commencing at some well-

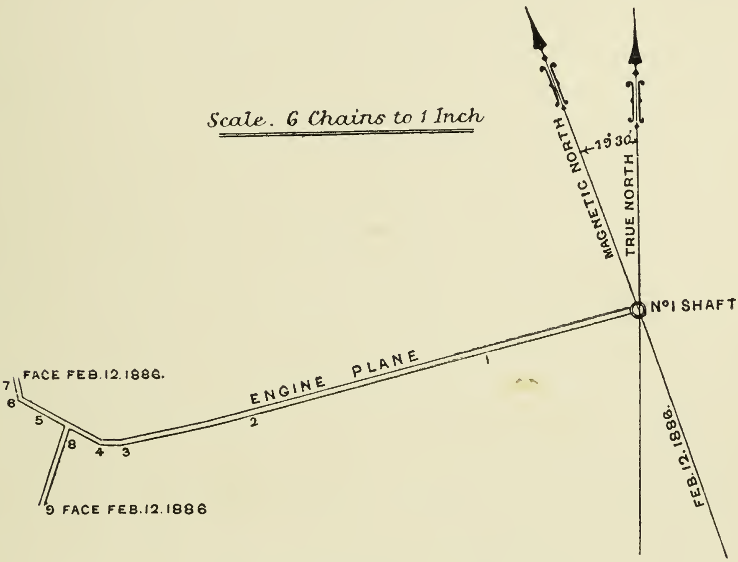


Fig. 358.—The Plotting of a Survey.

defined point on the surface may always have a "tie," that is, it may be closed at the starting point, and although it entails a little more labour where a doubling back and returning along a different route is resorted to, it may be well worth the labour. If such a survey be accurately made, on plotting it, the end of the last "set" line will exactly reach to, and coincide with, the beginning of number one "set" line. Similarly there may, where convenient, be intermediate checks or ties, taken from any one point of the main lines to others, and these checks on plotting an accurately made survey strengthen the proof of accuracy in the whole. If a slip has occurred in conducting the survey, on plotting, it will be discovered by the "set" lines not truly fitting where they should, and the error now known to exist must be discovered or a fresh survey made.

Again, a "tied in" survey may be tested by Euclid, for, "The sum of all the interior angles of any rectilinear figure, together with 4 right angles, are equal to twice as many right angles as the figure has sides." This is not so thorough a test as the plotting, because it checks only the angles taken and not the chainage, still it may sometimes be useful. For instance, it may be applied where the

plotting proved an inaccurate survey, and if the angles are found to be correct as surveyed, the error or errors must be in the chainage.

Underground workings do not afford the same facilities to "tie" surveys as are obtained on the surface, for however tortuous their course, the roadways must be traversed. Frequently, however, a "tie" can be obtained by following a roadway from its junction with another road until by means of branches the first-mentioned junction is returned to.

Advantage should be taken of these checks wherever they can be obtained.

Fig. 359 shows an underground survey "tied in" in the manner described.

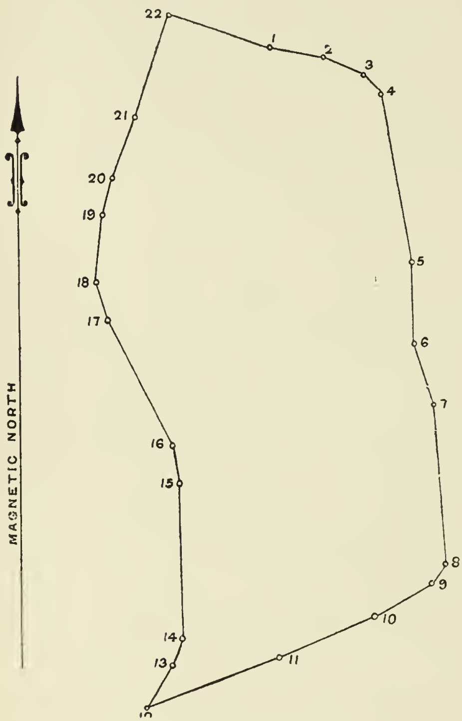


Fig. 359.—"Tied in" Survey.

	166 to 0 in 1	
22	19° 5′	(166)
21	21°	(96)
20	14° 45′	(60)
19	5° 40′	(105½)
18	342°	(61)
17	332° 55′	(217)
16	350° 55′	(56½)
15	359° 15′	(239½)
14	20° 25′	(41)
13	31° 35′	(78)
12	249°	(221)
11	247° 47′	(157½)
10	240° 20′	(103)
9	214° 33′	(29½)
8	176° 55′	(243)
7	163° 12′	(102½)
6	178° 58′	(127)
5	170° 11′	(261)
4	134° 27′	(35)
3	113° 26′	(67)
2	99° 51′	(84½)
1	109° 25′	(169)

The plotting of this survey proves it correct, but as an example for testing other surveys, the accuracy of the angles taken is proved below by calculating all the interior angles at the numbers of the "set" lines.

$180° - (109° 25' - 19° 5') =$	$89° 40'$	Interior angle at	22
$180° + (21° - 19° 5') =$	$181° 55'$	"	21
$180° - (21° - 14° 45') =$	$173° 45'$	"	20
$180° - (14° 45' - 5° 40') =$	$170° 55'$	"	19
$180° - (365° 40' - 342°) =$	$156° 20'$	"	18
$180° - (342° - 332° 55') =$	$170° 55'$	"	17
$180° + (350° 55' - 332° 55') =$	$198°$	"	16
$180° + (359° 15' - 350° 55') =$	$188° 20'$	"	15
$180° + (380° 25' - 359° 15') =$	$201° 10'$	"	14
$180° + (31° 35' - 20° 25') =$	$191° 10'$	"	13
$249° - (180° + 31° 35') =$	$37° 25'$	"	12
$180° - (249° - 247° 47') =$	$178° 47'$	"	11
$180° - (247° 47' - 240° 20') =$	$172° 33'$	"	10
$180° - (240° 20' - 214° 33') =$	$154° 13'$	"	9

$180^\circ - (214^\circ\ 33' - 176^\circ\ 55') = 142^\circ\ 22'$ Interior angle at 8
$180^\circ - (176^\circ\ 55' - 163^\circ\ 12') = 166^\circ\ 17'$,, 7
$180^\circ + (178^\circ\ 58' - 163^\circ\ 12') = 195^\circ\ 46'$,, 6
$180^\circ - (178^\circ\ 58' - 170^\circ\ 11') = 171^\circ\ 13'$,, 5
$180^\circ - (170^\circ\ 11' - 134^\circ\ 27') = 144^\circ\ 16'$,, 4
$180^\circ - (134^\circ\ 27' - 113^\circ\ 26') = 158^\circ\ 59'$,, 3
$180^\circ - (113^\circ\ 26' - 99^\circ\ 51') = 166^\circ\ 25'$,, 2
$180^\circ + (109^\circ\ 25' - 99^\circ\ 51') = 189^\circ\ 34'$,, 1

Total Interior angles $3{,}600^\circ$
Add 4 Right Angles $90^\circ \times 4 = 360^\circ$

Total $3{,}960^\circ$

No. of sides.
$22 \times (90 \times 2) = 3{,}960^\circ$

In plotting sections of considerable length the horizontal distances are not laid down on as large a scale as is necessary for the vertical heights above datum. A horizontal scale of 4 inches to the mile with one of 100 feet to 1 inch for the vertical scale is frequently used. In the following plotting of the levelling

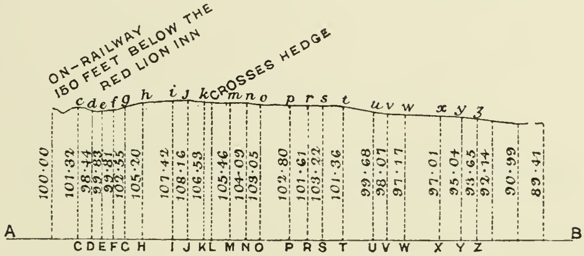


Fig. 360.—Plotting of a Levelling.

previously given to show the form of levelling book, a horizontal scale of $7\frac{1}{2}$ chains to 1 inch and a vertical scale of 150 feet to 1 inch have been adopted, but of course for a levelling of this length a much larger scale may be used.

It will be observed that A B, Fig. 360, is ruled for the datum line; on it are set off from A, the horizontal distances at the points, C, D, E, &c., according to the horizontal scale and through the points, C, D, E, &c., are drawn lines C*c*, D*d*, E*e*, &c., perpendicular to A B: on these lines are set off the vertical distances to the points, *c*, *d*, *e*, &c., according to the vertical scale of 150 feet to 1 inch, and the line, *c*, *z*, passing through all the points, *d*, *e*, *f*, *g*, *h*, *i*, &c., will represent the surface of the ground levelled over.

Different practices prevail in different parts with reference to the colouring of colliery working plans. In nearly all, however, the different boundaries have a thin edging of distinctive colour run round them in order to distinguish which particular taking the workings are advancing under, and to facilitate a calculation of the areas worked from time to time under that particular territory, as well as to draw attention to the near approach of workings to its extremities. The method of calculating these areas consists in dividing them into a series of triangles by ruling pencil lines on the plan, or on a tracing of the areas taken from the plan. The area of each triangle is obtained separately by multiplying the base by half the perpendicular height as measured by the scale on which the plan is made, and an addition of these separate areas of triangles gives the total acreage. It is usual to measure these triangles in links, and as

there are 100,000 square links in an acre, by pointing off 5 places of decimals, the result is obtained in acres and decimals. The decimal portion is then multiplied by 4, and five places of decimals marked off to the right again, any figure there may be to the left of the decimal point denoting roods. Again, multiplying by 40, and pointing off five decimal places, the figure or figures on the left of the decimal point will be perches. For example, suppose the acreage of some workings on the plan consisting of three triangles of the following measurements is required:—

	Base.	Perpendicular.
(1)	422 links	126 links
(2)	562 ,,	238 ,,
(3)	321 ,,	92 ,,

$$\text{For (1) } 422 \times \frac{126}{2} = \cdot 26586$$

$$(2)\ 562 \times \frac{238}{2} = \cdot 66878$$

$$(3)\ 321 \times \frac{92}{2} = \cdot 14766$$

$$\begin{array}{r} 1\cdot 08230 \\ 4 \\ \hline \cdot 32920 \\ 40 \\ \hline 13\cdot 16800 \end{array}$$

The area is thus ascertained to be 1 acre, 0 rood, 13·168 perches.

If the amount of coal contained in that area on a 4-foot seam is required, proceed thus:—

The difference in the specific gravity of coals obtained from different seams causes authorities to give different methods of calculating the yield. Newcastle coal is taken as weighing ·936 of a ton per cubic yard, or at 1,510 tons per foot thick per acre. An easily remembered rule is to take 120 tons per inch thick per acre (in cases where the specific gravity is not stated), but this is not quite so much as 1,510 tons per foot thick per acre. A liberal allowance is usually made in any calculations of this sort for loss in working and faults, and the amount of deduction will depend much upon the prevalence of faults or otherwise over the area to be calculated, from $\frac{1}{5}$th to $\frac{1}{3}$rd being usual. Adopting 1,510 tons per foot thick per acre, then $1{,}510 \times 4 \times 1\cdot 0823 = 6{,}537$ tons; from which deduct $\frac{1}{3}$rd, and there are 4,358 tons as the probable yield under the area calculated. If the seams lie at a high inclination, allowance must be made for it in calculating the quantities.

In some plans the workings have a different colour for each year's work put on them, others have only one colour, which is extended from time to time; the date of the survey is neatly printed on these, indicating the face at that time, and the colour is added on the workings as they advance from time to time; others again are not coloured at all. As a general rule, the less colouring the better, because moistening tends to shrink the paper.

In setting out the curves on the surface for the colliery railway much care must be exercised. If the sidings are to be cleared by the railway company's locomotives, the radius of the curves on which these are allowed to work by the Company's regulations must be ascertained, and the curves given a sufficiently long radius to meet such requirements. Much thought and some preliminary surveys may be wisely undertaken before constructing the railway, so that the best route be

selected and adopted. This route when decided on should be shown on the plan prepared for the purpose by marking on it, with a distinctive colour, the centre line of the proposed railway. This centre line must then be staked out on the ground and the levels taken along its course. From the levels taken a section is plotted, the various gradients decided on, and the amount of cutting and embankment ascertained and marked on the section.

If the survey of the land has been accurately made, no difficulty will arise in setting out the centre line of the railway on the ground. Measurements from the intersection of fences and other points may be used to fix the termination of straight portions of the railway, but the curves will require very careful treatment in pegging out.

One method of setting out curves on the ground is shown at Fig. 361. A dozen ranging rods, shod with iron, a couple of plumb-bobs, a surveyor's measuring rod, a Gunter's chain or steel measuring band, and the marking pegs will be required. The curve extends from the point B to K in Fig. 361, A B being the straight portion of the railway at one end of the curve, and K D that at the other end.

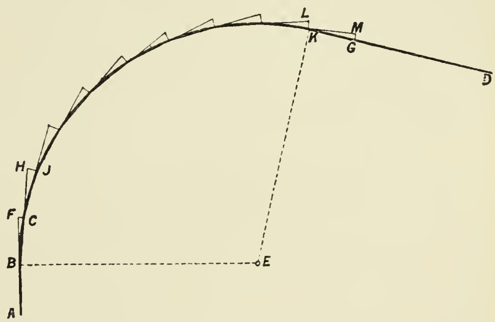


Fig. 361.—Setting out a curve.

By examining the plan in the office before going on the ground, the radius of the curve and the offset required in the setting out may be ascertained.

From B on the plan, draw the line B E at right angles to A B on the inside of the curve for any length. From K also draw K E at right angles to D K, till it intersects B E at E. E then is the centre of the curve B K, and the radius may be measured off by means of the scale. Divide the arc B K, into equal distances, B C, C J, &c., of a chain, or thereabouts. Continue the straight line A B to F, and make B F = B C. Then the offset from the tangent $F\,C = \frac{B\,C^2}{2\text{ radius}}$. Join B C, and continue the straight line to H. Make C H equal to C J. Then the offset $H\,J = \frac{C\,J^2}{\text{radius}}$. All the other offsets will be the same as H J throughout the curve to its end at K, but an additional one beyond the curve must be made to fix the position of the straight line K D. This offset M G is the same as F C, and is just one half the others.

Assuming the radius E B to be 20 chains, and the equal divisions along the arc to be one chain long, then $F\,C = \frac{100^2}{4{,}000} = 2{\cdot}5$ links, or expressed in feet $\frac{66^2}{2{,}640} =$ 1 foot 7·8 inches. $H\,J = \frac{100^2}{2{,}000} = 5$ links, or expressed in feet $\frac{66^2}{1{,}320} = 3$ feet 3·6 inches. The offset to be used throughout, then, is 3 feet 3·6 inches, except F C and M G, which must be half this, or 1 foot 7·8 inches.

Proceeding to the ground on which the curve is to be set out, first fix a ranging rod at A, another at B, and then in exact line with A B fix another rod at F, one chain from B, or such other distance as was decided on in dividing out the curve. Mark off the offset, 1 foot 7·8 inches, F C, and carefully test that the length of B C = B F. C then is the first point in the curve.

To determine the next, a rod must be set up at H in exact line with B C,

making C H equal in length to B F. Mark off the full offset of 3 feet 3·6 inches at H J, making C J = C H. A similar mode of procedure is carried on until coming to K, the remaining offset after this being M G, and is only 1 foot 7·8 inches. The continuation of K G to D gives the straight piece at that end of the curve.

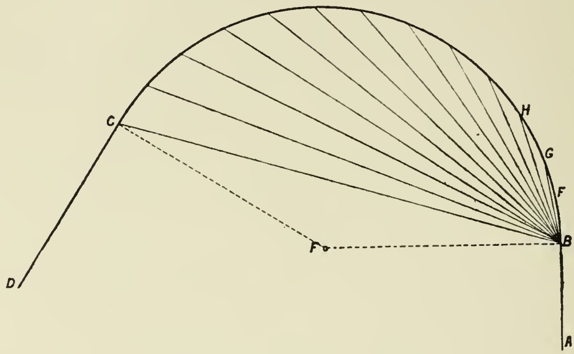


Fig. 362.—Setting out a Curve.

Another plan of setting out curves is shown at Fig. 362. The country must be open to admit of its adoption. A B and D C are two straight portions of the proposed railway communicating with each other by a curve B C, of which E is the centre. A theodolite is set up at B and directed towards F, which is one

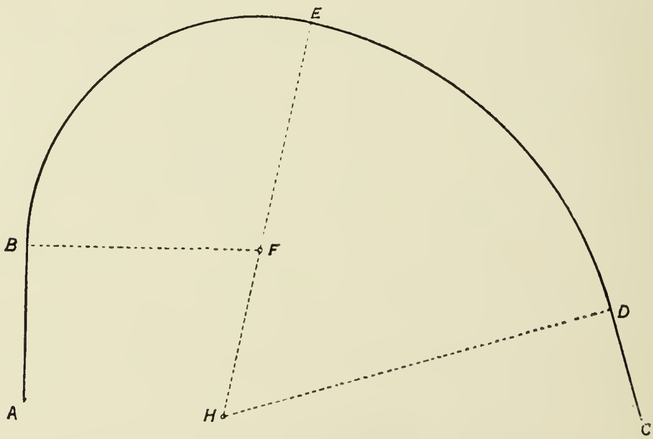


Fig. 363.—Setting out Curves.

of the even divisions into which the curve is divided. The angles F B G, G B H, &c., being equal when B F, F G, G H, &c., are all equal, the surveyor stands at the theodolite and sets off these angles, and directs two assistants with the chain where to set up the rods G, H, &c.

There are other methods of setting out curves, but that first described is the most commonly adopted, and it is applicable to the underground roadways when these require to be driven with a curve.

The curve separating two sections of straight railway may not proceed from a single centre. Fig. 363 is an example of this, where the curve B E is described from the centre F. The curve E D is continued with an increased radius, and to

determine its centre before describing it join E F and continue the line to H, making H E the desired new radius. From the centre H, describe the curve E D. The continuation of the railway D C must be at right angles to H D.

If an S curve is required as shown at Fig. 364, draw D G at right-angles to C D, and make D G equal the radius of the curve. From the centre G, describe the curve D F. Join G F, and continue the line to E, making E F equal the radius of the second curve. From the centre E, with the radius E F, describe the curve F B. The straight continuation of the railway, A B, will be at right angles to E B.

If an underground roadway has to be driven with, say, a 50-yard radius, the necessary offset must be short, as the roadways are narrow. The equal divisions

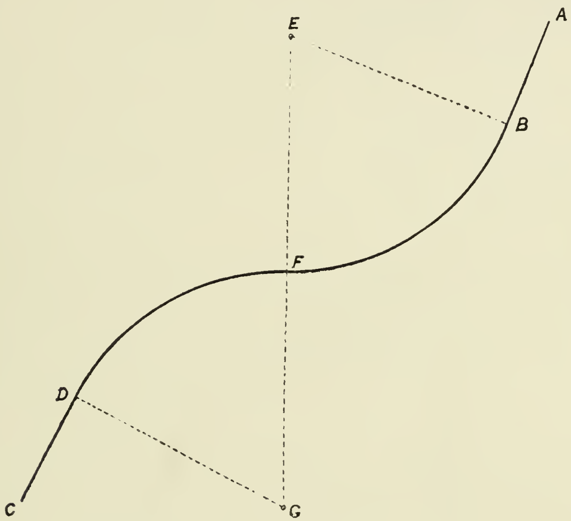


Fig. 364.—Setting out Curves.

of the curve must be short; in this instance take a yard. The first offset then, $\frac{1^2}{2 \times 50}$ = ·01 of a yard, or ·36 of an inch, and all others, except the last, will be double that. Bearings may be placed in the roof in a similar way to ranging the rods on the surface, but the bearings will have to be frequently changed, as the driving cannot proceed far with one instalment of them.

With regard to making geological sections, the mode of procedure is first to select the line of section, unless this is already some particular line which must not be deviated from. The line chosen will be influenced to a certain extent by the information afforded by different routes, keeping the line, however, as straight as practicable.

Perhaps by slightly deflecting from the straight line useful information may be made available by including the results of pit sinkings or workings. If, however, it is necessary to make a section from one given point to another in a direct line, which is unalterably fixed, the best must be made of the circumstances, and such information as can be obtained, used. A surface levelling between the two points may then be proceeded with, and plotted on a suitable scale, determined by the length of country over which the section extends, and the purpose for which it is required. On this plotting would be

shown the surface levels of the different pits crossed, and all other prominent objects. A careful scrutiny of the ground, quarries, cliffs, railway cuttings, and an examination of the fossils obtained from the rocks, &c., may then follow; the classification of the strata noted, with the amount of dip or rise in the direction of the line of section, and the direction of dip. By this means it is possible to calculate the thicknesses of the different rocks, and to plot them below the surface line previously shown on the drawing paper. In colliery districts, the pit sinkings and workings enable the surveyor to show the position of the seams of coal, the different strata, and also the faults met with, all of which require to be drawn.

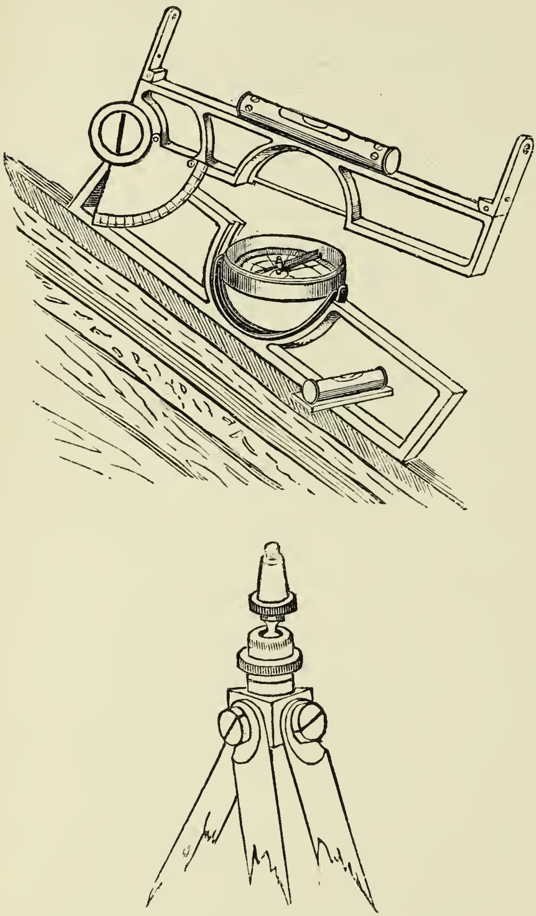


Fig. 365.—Louis's Improved Davis's Clinometer.

The section is outlined in pencil, and afterwards inked in with Indian ink, the main lines being shown in black, the faults with some other striking colour. Coal-seams are shown with bold, thick black lines, and the different strata are distinctly coloured. When the colours are all dry, the names of the coal-seams may be neatly printed over them, and either a reference printed in a corner of the paper identifying the strata represented by the different colours, or the names of the strata may be printed on them without using a reference. A title or heading is then printed along the top of the paper explaining the nature of the section and its scale or scales drawn or given.

A very convenient instrument for ascertaining the necessary particulars is Louis's improved Davis's clinometer, made by Messrs. John Davis & Son, of Derby, and shown at Fig. 365. In it a compass is placed in the lower portion of the clinometer frame, where it is carried by means of pivots on a brass arc, which may be revolved in the frame. This allows of the instrument being laid on strata of any dip, the rate of which will be ascertained by raising the upper portion of the clinometer frame until the air-bubble of the spirit-level placed on top is in the centre of its run, as shown in the drawing. The angle of dip may now be read by means of the graduated arc, whilst its direction is obtained by giving motion to the compass-box till it assumes a horizontal position in the under portion of the frame, and then reading the needle-bearing. The strike

of strata is usually determined by first ascertaining their maximum dip, and the compactness of this instrument allows it to be readily turned whilst readings are taken to fix the exact direction of dip in any one place. The bubble of the lower limb is mounted on a swivel, and this enables the instrument to be levelled both ways without being reversed. The compass-box is reversible in the under portion of the frame. The size of the clinometer is $6\frac{3}{4}$ inches long $\times$ $\frac{1}{2}$ inch wide $\times$ 3 inches deep, and weighs 1 lb. 2 ozs. It is provided with a tripod with ball-and-socket joint, 3 feet 10 inches long, and weighing 1 lb. 8 ozs. When

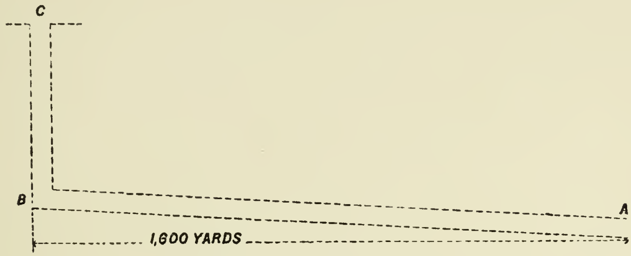


Fig. 366.—Driving to Air-shaft.

attached to the tripod it may be used as a Dumpy level where great accuracy is not required, or for ascertaining the inclination of a sloping adit, or undulations of the ground.

The following questions and answers, with which this chapter will be concluded, are such as are asked at examinations.

Question 128.—It is desired to drive from A to B, a distance of 1,600 yards (horizontal measurement), the driving to rise an inch in every 60 feet, and to put down an air-shaft, C B; what will be the depth of the shaft if its mouth is 350 feet above the level of A?

The driving would rise $\frac{1600}{20} = 80$ inches $= 6$ feet 8 inches between A and B (see Fig. 366), and 350 feet $-$ 6 feet 8 inches $=$ 343 feet 4 inches, which is the depth the air-shaft C B must be sunk.

Question 129.—What would be the variation of a plan's meridian when the bearing of two objects thereon with its meridian is N. 13° E., and the bearing of the same two objects on the surface is found by an instrument whose needle has 19° of West variation to be N. 8° E.?

The objects on the surface will form a bearing with each other of N. 11° W. by the true meridian, therefore $13° + 11° = 24°$, and the plan's meridian has 24° of West variation.

Question 130.—State in what way errors should be prevented from arising on plans owing to the variation, if the meridian shown on that plan be a magnetic one?

A surveyor should have some fixed points on the surface at long distances apart, one of which may be some prominent object, such as a church spire, and the other a stake driven into the ground in a convenient position to himself, free

from all influence likely to deflect the needle. Periodically he should fix his surveying instrument, by plumbing it over the stake, and take the magnetic bearing to the other object. By keeping a record of these at different dates he can make allowance when plotting his surveys for the alteration in the variation. It is a good plan to make an observation of the sun from the same stake, by doing which he can fix the true north point and find the angle made between it, the position in which his instrument is, and the other prominent object referred to. Having once established this, he may at any time afterwards find the difference between true and magnetic north. If he is in the habit of making surveys at places far apart, allowance must be made for the difference in longitude of those places.

Question 131.—Describe any method for finding the true meridian ?

In Lintern's *Mineral Surveyor and Valuer's Guide*,* the following method for finding the true meridian at any place whose latitude is known, is described. The method is by equal altitudes of the sun or a fixed star. "The theodolite being fixed in a position selected as one of the points in the desired line, measure the horizontal angle from the said line to the sun or fixed star (whichever is used), when it is not near the highest or lowest point of its apparent daily course, and take also the altitude, adjusting the intersection of the hairs of the telescope to it, in some marked and definite manner. Leave the limb clamped, and let the instrument remain quite undisturbed until the sun or star is approaching the same altitude at the other side of its apparent circular course. Then, without moving the body of the instrument, unclamp the limb, and again direct the telescope towards the same object, and follow it with the aid of the tangent screw until the cross-hairs correspond precisely as before with the same relative position upon the disc of the object, as in the first observation ; this being done, read off the horizontal measure of the angle between the assumed line and the new direction of the observed object; the mean between the two horizontal angles will define the position of the true meridian, *if a star has been observed.*

"If the *sun* has been observed, a correction is required in consequence of the sun's change of declination. When that declination changes towards the north, the approximate direction of the meridian, as found by the foregoing method, is too far to the right ; if declination changes towards the south, it is too far to the left.

"The required correction is found by the following formula :

$$\frac{\text{Change of sun's apparent declination}}{2} \times \text{sec. latitude} \times \text{co-sec. } \tfrac{1}{2} \text{ angular}$$

motion of the sun between the observations."

An example will now be given showing an application of the method. Date of observation, July 20th, 1886. By consulting the nautical almanack for the date given, the sun's apparent declination is stated to be changing towards the south at the rate of $11' \, 28''$ per day. Time between the observations, which were taken in Springfield garden, Pontypridd, 6 hours. Change of apparent declination for six hours $= 11' \, 28'' \times \frac{6}{24} =$ say $3'$. Theodolite fixed over a stake in the garden, from which Pontypridd church spire was observed. The upper plate being securely clamped to the lower, with the vernier at zero, the instrument was directed towards the church, and the lower clamping-screw tightened with the hairs of the telescope correctly bisecting the top of the church spire. This being done, the upper plate was loosened, and an angle from the church to the sun obtained at that time, 9.15 A.M. Reading, $269° \, 52'$. At 3.15 the upper clamping-screw was slackened, and the telescope, with the vertical limb undisturbed, directed to the sun ; on its edge appearing in contact with the hairs of the

* London : Crosby Lockwood & Son.

instrument, the reading of the angle was recorded as 41° 45′. The angle contained between the two readings therefore was (360 − 269° 52′) + 41° 45′ = 131° 53′.

For the correction we have—

Log. of $\frac{3'}{2} = 90''$	=	1·954243
„ sec. 51° 36′ 15″ (N. latitude of Pontypridd)	=	10·206845
„ co-sec. $\frac{1}{2}$ of 131° 53′	=	10·039467
		2·200555 = Log. of

158·7, or say 2′ 30″. Therefore the approximate direction as found by the observation is too far to the *left* by 2′ 30″.

∠ from church to 1st observation 360 — 269° 52′	=	90° 8′
„ „ 2nd „	=	41° 45′
Difference		2) 48° 23′
Difference halved		24° 11′ 30″

but being $2\frac{1}{2}$ minutes too much to the left, the correct reading should be 24° 9′. The magnetic bearing from the same point of observation was taken to Pontypridd church by the same instrument at the same date as S. 43° 12′ W. from which deduct 24° 9′

Making the magnetic declination 19° 3′

Question 132.—Describe the underground and surface levelling staves, and state how you would proceed to level underground with the level and staff?

The staff used in underground operations is usually made about 9 feet long, and is in three pieces, which are connected together like the joints of a telescope, and these close down to 3 feet 6 inches. It is graduated into feet, tenths, and hundredths. The figures appear in an inverted position as seen through the telescope, but the surveyor soon gets accustomed to this. To avoid this some surveyors prefer having an additional lens placed in the telescope, others have the staff figures arranged so as to appear the right way up when seen through the telescope. The staff used on the surface is of the same description as that used underground, being made in three pieces, the two upper sliding into the lower like the joints of a telescope, and being graduated into feet, tenths, and hundredths. The total length when out is 14 or 16 feet, and it closes to 5 or 6 feet. Staves of 18 and 20 feet are occasionally used. The method of proceeding with an underground levelling is as follows:—

An assistant holds the staff in an upright position at the shaft, and the levelling instrument having been set up truly level in the road which it is desired to level, a sight of the levelling staff is taken and the result entered in the book. The levelling staff is then moved along the road to where its inclination changes, or to where, owing to a change in the direction of the road, it is impossible to see farther, and a sight from the instrument gives the reading there. The fore-sight, as this reading is called, is entered in the levelling-book an example of which has been given. The difference of level between the two points is thus obtained, and this is either added to or subtracted from the level of the starting point, known to be a certain number of feet above the datum line, which may be the Ordnance datum or have some clear and well defined relation to it. At most collieries it is necessary to adopt a datum line which is 1,000 or 2,000 feet below that of the Ordnance. A number of sights is sometimes taken with the instrument

in one position, but after the fore-sight is booked, the instrument is lifted and carried to a position inside the fore-sight, set up level there, and the staff which has remained on the fore-sight last observed is now turned round to face the instrument but rests on the same part of the road as before, or what is preferable in a shoe used for the purpose. This reading being entered as a back-sight, any intermediate sights may be taken, and the last will be a fore-sight. This method continues throughout the levelling. Some inconvenience and liability to error arises from the fact that owing to the varying heights of underground roads portions of the staff have occasionally to be pushed in, and these may be fractions of a foot for which allowance must be made when entering the readings. This has led to one or two improvements in form for an underground levelling staff.

Fig. 367.—Front view.

Fig. 368.—Side view.

Jee's Underground Levelling Staff.

One recently brought out by Mr. James R. Linsley, the surveyor at Cramlington Collieries, consists in dividing the staff into an upper and lower division, the former sliding into the latter. To the top of the sliding portion is fixed a spring drum, on which coils a tape, whose lower end is attached to the top of the lower division of the staff. The figures and divisions are painted on this tape the same as on the staff, and in roadways of varying height the upper portion of the staff may be opened until close to the roof, and when this is done the reading of the staff is continuous from the floor upwards.

Mr. G. J. Jee's underground levelling staff is somewhat similarly constructed, but is made in two sizes by Messrs. J. Davis & Son, Derby, the 9-foot size closing down to 3 feet 6 inches, and the 6-foot to 2 feet 6 inches. Fig. 367 shows a front and Fig. 368 a side view of the staff. Both sizes consist of three divisions. The 9-foot staff has a 2-inch band attached to the top of the lowest division, which is 3 feet long, and as the middle division is raised the band uncoils off the brass drum shown in the figure. This drum is placed just below the top of the top division of the staff, and in unwinding off it the band is carried through a small brass roller on top of the division. The band is graduated upwards, and when the middle division of the 9-foot staff is out, reads continuously up to 5 feet 8 inches. If the roadway permit of it, after the middle division has been opened to its full extent, the top one may be drawn out, and the same band further uncoiled till it reads continuously to 9 feet.

Quite recently another form of levelling staff for use in mines has been introduced. In it the figures are painted in dark colours on a background of ground glass or other transparent material. When being used a light is placed behind the staff, and this gives the surveyor a better opportunity of making his observations.

Question 133.—Should the workings be too low to admit the use of the level and staff, how would you proceed?

The usual method is by means of a straight edge, which may be 6 or 12 feet

long according to the steepness of the measures, and by an ordinary mason's level. The straight edge is laid along the road (with the mason's level placed on it), and then one end is lifted off the ground till it is in a truly level position as shown by the spirit level resting on it; a two-foot rule or other measuring strip is then used for taking the height the one end of the straight-edge has been raised, and the amount is entered in the book as a rise or fall. If the leading end of the straight edge, or the inside end going "inbye," has been raised, the road falls, but if the outside end is raised, the road rises. The straight edge is then moved forward another length, and the same process repeated, and so on throughout the levelling. This is only an approximate method of levelling, and too much reliance must not be placed on it.

Question 134.—Sketch on paper as near as you can, without the aid of scale or protractor, the following bearings of a survey (1) N. 50 E., 46 links; (2) S. 26 E., 63 links; (3) S. 20 W., 85 links; (4) S. 56 W., 76 links.

It is not expected that the candidate without a scale or plotting instruments will get a very correct answer to this, but he may get an approximate result. Thus, consider the top of the paper on which the answers are being written as the north end and the ruled lines will be east and west. A line half way between these will represent an angle of 45°, and half way again $22\frac{1}{2}$°, and for the rest he may guess as nearly as possible. With regard to the distances, he must only consider them relatively, unless a rule or scale be used. No. 1 being 46 links, whatever length is chosen to put this on paper he must make No. 2 $\frac{63}{46}$ = nearly $1\frac{1}{2}$ times as long, No. 3 $\frac{85}{46}$ nearly twice as long, and No. 4 would be not quite so long as No. 3. Bearing this in mind the result obtained would be in some such form as shown at Fig. 369.

Fig. 369.—Approximate Plotting of Bearings.

Question 135.—State the different methods of connecting the underground workings with the surface boundaries.

First, by the magnetic meridian. Secondly, by suspending two copper wires from a balk at the top of the pit, and which have heavy weights attached to them in the sump. When the wires are steady, the balk on the surface should be turned round until the wires are in a line with the underground road, as determined by a light seen from the shaft along the road. Marks may then be made in the roof in a line with the wires, and rods may be ranged on the surface in a line with the same wires, and pegs afterwards put in so that the surveyor may have a base line on the surface and underground to refer to at any time. A third method is that of connecting them by means of a transit instrument, but this is not frequently done by ordinary surveyors. A fourth, and undoubtedly the best method where circumstances admit of its being adopted, consists in con-

necting them by means of two or more shafts at a considerable distance apart, and, of course, the more direct the underground connection between the shafts the better. The bearing which the one shaft makes with the other on the surface, and their relative position with regard to the boundaries having been accurately determined, proceed to survey between the shafts and elsewhere underground. Plot the surface and underground survey on separate sheets of paper, trace the plotting of the underground survey and place the tracing on the surface plan, with the one pit of the tracing correctly adjusted over the same pit of the surface survey, then the other pit or pits of the tracing ought, when it is turned in proper position, to fall on the pit or pits of the surface survey. If they do not, some error exists, and the surveys must be again made. If they do, the underground roads may be pricked off from the tracing to the plan, while the pits of the tracing and plan exactly coincide, and the workings will thus be placed relatively right to the surface boundaries.

Question 136.—Explain what is meant by a scale of $\frac{1}{2}$ inch to the chain.

It means that on any straight line of $\frac{1}{2}$ inch long of the plan the actual measurement is a chain, or 66 feet, and therefore on 1 inch, 2 chains, or 132 feet, of actual measurement is represented.

Question 137.—Suppose a driving is going towards an old waste which is shown on a plan 30 years old, explain the precautions to be taken as regards meridian.

Reference may be made to the magnetic declination for the particular year in which the plan was made if it bears date, which it would appear from the question it does. Knowing the declination then and the declination now, bearings may be put on any underground road to direct its course clear of any wastes it is desirable to avoid or towards any particular point it is desired the driving to hole into. If the plan have no date fixed to it, the variation of its meridian may be determined by observing the bearing which any two objects make on the plan by its meridian, and also the bearing on the surface which the same two objects make with each other, by a needle whose declination is known.

Question 138.—What is the present magnetic variation?

The magnetic variation at Greenwich for the beginning of the year 1890 was 17° 20′ W., but it is constantly changing, and this will not apply to other years nor to all other places for the same year.

Question 139.—Find the quantity of coal in one acre of a seam of the following section:—

Top coal . . .	2 feet	3 inches.
Band . . .		10 ,,
Bottom coal . .	1 ,,	9 ,,
Total	4 ,,	10 ,,

taking the specific gravity of coal at 1·25.

A cubic foot of water weighs 62·5 lbs. and therefore a cubic foot of coal whose specific gravity is 1·25 is $62·5 \times 1·25 = 78·125$ lbs. In one acre there are 4,840 square yards, or $4840 \times 9 = 43,560$ square feet. The actual thickness of the coal in the seam, disregarding the band, is 2 feet 3 inches + 1 foot 9 inches =

4 feet, and $43{,}560 \times 4 = 174{,}240$ cubic feet of coal in an acre, and as one such cubic foot weighs 78·125 lbs., the weight of the whole is $\frac{174{,}240 \times 78{\cdot}125 \text{ lbs.}}{2{,}240}$ $= 6{,}077$ tons, the total weight per acre.

Question 140.—If pillars are left 30 yards by 18 yards, the width of the headways being 2 yards and bords 4 yards, what percentage is got in the first working?

By sketch Fig. 370, the block of coal before the headways and bords are out will be 32 yards $\times$ 22 yards $=$ 704 square yards. The pillar remaining is $30 \times 18 = 540$ square yards and the coal taken out is $704 - 540 = 164$ square yards. Therefore as 704 : 164 :: 100 : 23·3, which is the percentage obtained in first working.

Question 141.—If 20 per cent. is allowed for loss of working and 31 per cent. screened out at bank, how many chaldrons of round coal will a foot thickness of a seam yield per acre?

$20 + 31 = 51$ per cent. of small and lost, therefore there would be 49 per cent.

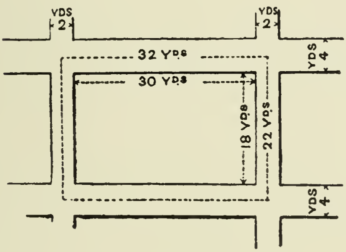


Fig. 370.—Sketch of a Pillar with Dimensions marked.

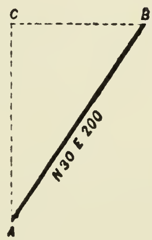


Fig. 371.—Plotting of a Bearing.

of large coal yielded. A seam of coal 1 foot thick contains 1,510 tons per acre, and since a chaldron weighs 53 cwt., then $\frac{1{,}510 \times 20}{53} =$ nearly 570 chaldrons. As 100 : 49 :: 570 : 279·3 chaldrons of large coal per acre.

Question 142.—What are traverse tables?

These are tables giving the northing, southing, easting, or westing, each bearing of a survey makes. Suppose, for instance, a bearing of N. 30 E. to be taken and its distance is 200 links. Let A B in the accompanying sketch (Fig. 371) represent such bearing plotted. Then AC is the north meridian. If now from B a line is drawn at right angles to AC to meet AC in the point C, the northing of the bearing AB for the distance indicated is measured by the length of AC, and similarly its easting is measured by the length of CB. So with southings and westings when the bearings of lines are in that quadrant, or with southings and eastings, or northings and westings. Refer to any traverse tables now under the proper number of degrees and for 200 links will be found for the example given, AC $=$ 173·2 links and CB $=$ 100.

The results taken from these tables of a number of survey sets are added together so that it is possible to tell at any point of the survey the northing,

southing, easting and westing from the starting to that point or from any other intermediate point passed in the survey.

Question 143.—In a heading going S. 45° E., what must be the course of a cross heading going at right angles on the north side?

N. 45° E. must be the desired bearing.

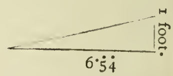
Question 144.—What is the use of the vernier? Describe the method of using it to find the 120th part of a degree.

The vernier is a contrivance for measuring the fractional parts of a graduated scale, and is connected with various scientific instruments, as the theodolite, sextant, barometer, &c. It is so constructed as to slide evenly along the graduated limb of an instrument, and enables the observer to read off the subdivisions of a scale with remarkable nicety. The divisions in the vernier are usually shorter than those upon the limb to which it is attached, the length of the graduated scale of the vernier being exactly equal to the length of a certain number ($n-1$) of the divisions upon the limb, and the number (n) of divisions upon the vernier being one more than the number upon the same length of the limb.

To find the 120th part of a degree, or 30″, the vernier should be divided into half divisions, and after sliding it along the limb to the position desired, the degrees and minutes may be read, and also the nearest half minute, by observing the divisional line of the limb that exactly coincides with a divisional line of the vernier.

Question 145.—If a heading A to B rises $5\frac{1}{2}$ inches per yard for 60 yards, from B to C, $2\frac{1}{2}$ inches per yard for 40 yards, what is the inclination from A to C, and the depth of cutting at B? Assuming the cutting to be 6 feet wide and every 14 cubic feet of the cutting weighed one ton, how many tons would such cutting yield?

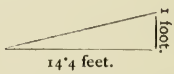
A rise of $5\frac{1}{2}$ inches per yard $= \dfrac{36}{5\frac{1}{2}} = 1$ in $6\cdot\dot{5}\dot{4}$. Therefore for every $6\cdot\dot{5}\dot{4}$ feet of horizontal measurement there would be a rise of 1 foot, thus,



The hypothenuse of such triangle will measure $\sqrt{6\cdot54^2 + 1^2} = \sqrt{42\cdot843 + 1} = 6\cdot6214$ feet measured along the slope, and as the full length of that slope is said to be 60 yards = 180 feet, its horizontal measurement is

As $6\cdot6214 : 6\cdot\dot{5}\dot{4} :: 180 : 177\cdot93$ feet.

Similarly in the next section of the heading, where there is a rise of $2\frac{1}{2}$ inches per yard $= \dfrac{36}{2\frac{1}{2}} = 1$ in $14\cdot4$. Therefore, for every $14\cdot4$ feet of horizontal measurement there would be a rise of 1 foot thus,



$\therefore \sqrt{14\cdot4^2 + 1^2} = \sqrt{207\cdot36 + 1} = 14\cdot4346$ feet measured along the slope for each $14\cdot4$ feet of horizontal measurement, and as the full length of that slope is stated to be 40 yards = 120 feet its horizontal measurement is As $14\cdot4346 : 14\cdot4 :: 120 : 119\cdot71$ feet.

Fig. 372 will further assist the answering of this question.

The point C is horizontally distant from A $177{\cdot}93 + 119{\cdot}71 = 297{\cdot}64$ feet = 99·21 yards.

$$\begin{array}{llll} \text{B will be above the point A} & \dfrac{177{\cdot}93}{3 \times 12} \times 5{\cdot}5 = & 27{\cdot}184 & \text{feet.} \\ \text{C} \quad ,, \quad ,, \quad ,, \quad \text{B} & \dfrac{119{\cdot}71}{3 \times 12} \times 2{\cdot}5 = & 8{\cdot}3 & ,, \\ \hline \text{C} \quad ,, \quad ,, \quad ,, \quad \text{A} & & 35{\cdot}484 & ,, \end{array}$$

A cutting then having a uniform gradient between A and C would rise $\dfrac{35{\cdot}484}{99{\cdot}21} = {\cdot}357$ of a foot per yard = 4·284 inches per yard.

To find the depth of cutting at B.

$\dfrac{177{\cdot}93}{3} = 59{\cdot}31$ yards, and $\dfrac{59{\cdot}31 \times 4{\cdot}284}{12}$ or $59{\cdot}31 \times {\cdot}357 = 21{\cdot}174$ feet. $27{\cdot}184 - 21{\cdot}174 = 6{\cdot}01$ feet. Therefore the floor of cutting would be 6·01 feet below the heading floor at B.

To find the cubical contents of the rubbish which would come from such cut-

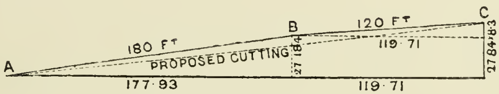
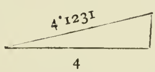


Fig. 372.—Sketch showing Gradients of Heading.

ting, beginning at 0 at A, increasing to 6·01 feet at B, and then decreasing to 0 at C, we have $180 + 120 = 300 \times \dfrac{6{\cdot}01}{2} \times 6$ the width = 5,409 cubic feet, and since 14 cubic feet weigh 1 ton $\dfrac{5{,}409}{14} = 386\tfrac{5}{14}$ tons, which is the total weight obtained from the cutting.

Question 146.—What is the horizontal base and vertical height of an inclined plane 30·75 chains long and rising 1 in 4?

Here $\sqrt{4^2 + 1^2} = \sqrt{16 + 1} = 4{\cdot}1231$ measured along the slope for every 4 measured horizontally, thus



. As the whole length of slope is 30·75 chains, then $4{\cdot}1231 : 4 :: 30{\cdot}75 : 29{\cdot}832$ chains for the horizontal base, and the vertical height is $\dfrac{29{\cdot}832}{4} = 7{\cdot}458$ chains.

Question 147.—Two shafts are separated by natural strata, and the workings are approaching the boundary; describe the method of making a check survey.

In the case of two shafts separated by natural strata and having an underground communication between them on the same level as the road leading from one of them to the workings approaching a part of the boundary, a surveyor would take

advantage of the connection between the two shafts so as to strengthen the proof of accuracy in the survey, and to ensure that the barrier left (if any) should be of the width desired.

The method would be as follows. First, a very careful survey of the surface should be made, with a true and carefully adjusted instrument (preferably a transit theodolite), such survey to include the two pits, which call No. 1 and No. 2, and the portion of the boundary which an inspection of the working plan would show to be necessary, and taking care to include rather more of the boundary lines than actually required. The method of carrying out the details of the surface survey would be decided by the particular circumstances, and the lines chosen would be those offering the fewest obstacles to a successful survey, and therefore calculated to promote accuracy. These lines would pass near the portion of the boundary required, so as to reduce the offsets as much as practicable, and when completed they would contain proof of their accuracy by the "tie in," so that the surface survey would be complete in itself, and inde-

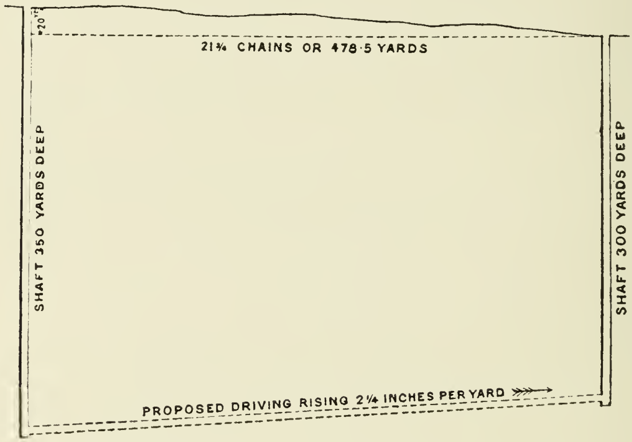


Fig. 373.—Sketch showing a Driving between two Shafts.

pendent of the underground survey. If the pits were in a mountainous district, and it commended itself to the surveyor's judgment, he might in preference to running traverse lines as indicated, measure accurately a long base line in a valley, and fix the position of the pits and two extreme points of the portion of the boundary required, by means of angles taken off the base line; and a few traverse lines could be run along the boundary between the extreme points afterwards.

The method of procedure in the underground workings would be by traversing, taking care to use the same instrument as when making the surface survey, and if, say, No. 2 shaft is that from which the underground road leads into the workings approaching the portion of boundary already surveyed, the surveyor should commence the survey at No. 1 pit (supposing there to be no pumps in it, and the road leading therefrom to be clear of iron pipes, rapper wires, engine plane ropes and other substances of magnetic attraction), traverse the road to No. 2 pit, and continue on to the workings in question. If, from the presence of iron near No. 1 pit, the surveyor deemed it advisable, he would commence the underground survey at the face (which is usually free or easily freed from iron) of the boundary workings, or in some disused road, traverse "out bye" to No. 2 shaft

and continue the survey to No. 1 pit; and if this were done, it would be convenient, but by no means necessary, to plot the underground before the surface survey. Should circumstances admit of a "tie" of any sort in the underground workings, full advantage should be taken of it, so as to strengthen the proof of the whole survey, but the position of the two shafts as ascertained on the surface, and also as ascertained by the underground survey, ought of course to agree, and if they are at some distance apart, a carefully made survey as now indicated, and with all its ties when plotted fitting in, would leave little more to be desired.

Question 148.—At the bottom of a pair of shafts 300 and 350 yards deep, it is required to drive a drift from one to the other; the distance between the shafts is $21\frac{3}{4}$ chains and the difference of surface level is 20 yards, what is the inclination of the heading?

This question is capable of two answers, the question not being complete in

Fig. 374.—Sketch showing a Driving between two Shafts.

itself. It is not enough to state that there is a difference of surface level of 20 yards; it is necessary also to know whether the shallower or deeper pit top is at the higher level. First, supposing the deeper pit top to be 20 yards above the 300-yard pit top, then Fig. 373 will assist the answer now given.

$350 - 320 = 30$ yards, bottom of 300-yard pit above bottom of 350-yard pit. Distance apart $21\frac{3}{4}$ chains $\times$ $22 = 478{\cdot}5$ yards. $\dfrac{30 \times 3 \times 12}{478{\cdot}5} = 2{\cdot}25$ or $2\frac{1}{4}$ inches rise per yard from the 350-yard shaft bottom to the 300-yard shaft bottom.

Assuming, however, that the 300-yard shaft is at the higher surface level, it would affect the answer very materially, as the sketch (Fig. 374) and following working will show.

In this case $350 + 20 = 370$ and $370 - 300 = 70$ yards the bottom of the 300-yard pit is above the bottom of the 350-yard pit. Then $\dfrac{70 \times 3 \times 12}{478{\cdot}5} =$ $5{\cdot}26$, or $5\frac{1}{4}$ inches rise per yard from the bottom of the 350-yard pit to that of the 300-yard pit.

Question 149.—The chord of a segment of circle is 60 feet, and the versed sine 78 inches. What is the radius of the circle?

The following formulæ are applicable to segments of circles.

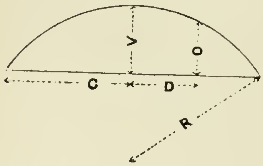


Fig. 375.—SEGMENT OF CIRCLE.

$V =$ Versed sine.
$C =$ Semi-chord.
$R =$ Radius.
$O =$ Any ordinate.
$D =$ Distance of ordinate from centre.

$$O = \sqrt{R^2 - D^2} - (R - V).$$

$$R = \frac{V^2 + C^2}{2V}, \text{ or diameter } = \frac{V^2 + C^2}{V}.$$

$$V = R - \sqrt{R^2 - C^2}.$$

$$\text{Area of segment} = \frac{4}{3}\frac{V}{} \sqrt{(0{\cdot}626\ V)^2 + C^2}.$$

Therefore, in the question given

$$R = \frac{6{\cdot}5^2 + 30^2}{2 \times 6{\cdot}5} = \frac{6{\cdot}5}{2} + \frac{30^2}{2 \times 6{\cdot}5} = 3{\cdot}25 + 69{\cdot}23 = 72{\cdot}48 \text{ feet.}$$

Question 150.—The radius of a circle is 72·48 feet, and the length of chord 60 feet, what is the versed sine?

$$\begin{aligned} V &= 72{\cdot}48 - \sqrt{72{\cdot}48^2 - 30^2} \\ &= 72{\cdot}48 - \sqrt{5{,}253 - 900} \\ &= 72{\cdot}48 - \sqrt{4{,}353} \\ &= 72{\cdot}48 - 65{\cdot}98 = 6{\cdot}5 \text{ feet or 78 inches.} \end{aligned}$$

Question 151.—If, where the workings of a coalfield proceeding in the direction of the full rise which is 1 in 10 and due north, the main levels are "set away" 1 in 130, what are the bearings of the levels?

Take a small ivory or boxwood protractor which has a scale of chords and other scales marked on it, and after setting the two legs of a pair of compasses at

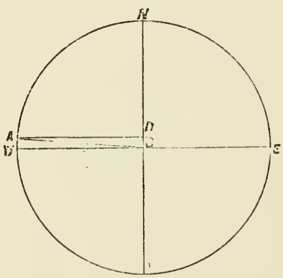


Fig. 376.—SKETCH SHOWING DIRECTION OF MAIN LEVELS.

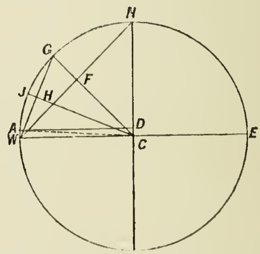


Fig. 377.—SKETCH SHOWING DIRECTION OF MAIN LEVELS.

60 degrees by the scale of chords, describe the circle NWSE from the centre C in Fig. 376. From a point W in the circumference draw a line through the centre C to the circumference E, and draw the lines CN and CS at right angles to WE, joining the circumference at N and S.

Let N represent north and CN will represent the full rise of the seam, which consider as being 130 long. By means of a scale take the point D, making CD equal to 10, or $\frac{1}{13}$th of CN. Draw DA parallel to CW, cutting the circumference

at the point A. Join CA, and the line CA will represent the direction of one of the levels, for the point A will be 1 above C, and CA is 130 long. Place one leg of the compasses on W, and extend the other to A, and then measure that distance on the same scale of chords used before, and it will read about $4\frac{1}{2}°$; or the lines CW and CA may be continued on the paper a suitable length in a direction from C and the protractor placed on the paper with its centre at C and the angle ACW may be thus read off, and it will be found to be about $4\frac{1}{2}°$. The bearing of the level CA then is $90 - 4\frac{1}{2} = 85\frac{1}{2}°$ N.W. approximately, because it cannot be read to exact minutes this way. In the same manner a level course going on the opposite side from C may be shown to have a bearing of N. $85\frac{1}{2}°$ E.

If a protractor is not allowed, or is not at hand, a very close approximation to a correct answer may be obtained without it, thus:—

From the centre C, Fig. 377, with the radius 130, describe the circle NESW. Let NS represent the north and south, and E and W the east and west points respectively on the circle. Make CD equal to 10, and draw DA parallel to CW, cutting the circumference at the point A. Join CA and WN. Then CA will represent the direction of the level course and A will be 1 above C or W.

Bisect the chord WN in F and join CF. Continue the line CF to cut the circumference in G. Then the length of the chord WN is $\sqrt{130^2 + 130^2} = 183{\cdot}847$, and since the point N is 13 above C, the point F is 6·5 above C. The angle CWF is equal to the angle WCF, therefore the side CF is equal to the side WF, and WF is $\frac{183{\cdot}847}{2} = 91{\cdot}924$. As F is 6·5 above C, it will be found that the point G is as $91{\cdot}924 : 130 :: 6{\cdot}5 : 9{\cdot}1924$.

Now join GW, and its length will be $\sqrt{91{\cdot}924^2 + (130 - 91{\cdot}924)^2} = \sqrt{91{\cdot}924^2 + 38{\cdot}076^2} = 99{\cdot}17$. Bisect WG in H and WH $= \frac{99{\cdot}17}{2} = 49{\cdot}585$. Join CH, and continue CH to cut the circumference in J. The point H is $\frac{9{\cdot}1924}{2} = 4{\cdot}5962$ above C or W. Find the versed sine JH in the segment G by the formula given in Answer 149, thus $130 - \sqrt{130^2 - 49{\cdot}585^2} = 9{\cdot}828$. Therefore CH $= 130 - 9{\cdot}828 = 120{\cdot}172$. As H is 4·5962 above C, the point J is as $120{\cdot}172 : 130 :: 4{\cdot}5962 : 4{\cdot}972$.

The angle GCW contains $45°$ and JCW $22\frac{1}{2}°$, and approximately the proportion of degrees for the angle ACW will be found, thus as $4{\cdot}972 : 1 :: 22\frac{1}{2} : 4{\cdot}525$, or, say, $4\frac{1}{2}°$, and therefore the bearing of the level CA is approximately $90° - 4\frac{1}{2}° = 85\frac{1}{2}°$ N.W. The level proceeding on the opposite side will bear approximately N. $85\frac{1}{2}°$ E.

The most satisfactory, and indeed the only strictly accurate answer to a question of this sort is obtained from a solution by trigonometrical rules, involving the use of tables, &c.

CHAPTER XIII.

SAFETY-LAMPS AND FIREDAMP DETECTORS.

The Davy Lamp—The Clanny—Morgan's—Protector—Pieler—Gray's—Hepplewhite-Gray—Marsaut—Mueseler—Evan Thomas—Clifford—McKinless—Cryptograph Lock—Cuvelier's Patent Lock—Examining and Testing Safety-lamps before going into the Mine—Patterson's Testing Apparatus—Primary and Secondary Portable Electric Safety-lamps—Garforth's Firedamp Detector—Liveing's Firedamp Detector—Maurice's Firedamp Indicator.

SAFETY LAMPS.

So many different kinds of lamp have been invented that it would be impossible here to describe them all. Each, however (except the Electric Safety-lamp, and McKinless's Gauzeless Lamp), depends on Sir Humphrey Davy's discovery, that through a fine wire gauze, having 784 apertures to the square inch, formed by the crossing of 28 parallel wires, the flame of ignited gas would not pass unless acted upon by a strong current of wind. The gauze of the *Davy* lamp is constructed of iron wire about $\frac{1}{50}$th of an inch in diameter. Notwithstanding the number of lamps in use, the Davy, protected from currents by a proper covering, is still found to be, under certain circumstances, an excellent lamp. It is very useful in the hands of the man who has been appointed to examine the working places. Most modern lamps go out in an explosive atmosphere, and no wonder, for they are placed in the hands of the workmen whose energies are directed to coal-getting, &c., rather than in watching their lamps. With the fireman it is different. He is, or at least ought to be, a prudent and careful man, who has had considerable experience of firedamp, and has probably been appointed on that account. He detects the gas with the Davy, and withdraws from the point of discovery quietly, unless the quantity appears large, in which case he puts out the flame himself by drawing the wick down into the oil-holder with the pricker. He on no account attempts to blow it out. It must be remembered that if the Davy lamp be kept for a short time in an explosive atmosphere the gauze becomes red-hot, and in that state a slight movement might cause the flame to pass, and ignite the gas outside. Again, if the lamp be placed in a strong current of air, the flame will be forced out of its proper position, and the end of it will then be directed towards the gauze, the wires of which will become heated to such an extent that the flame of the gas inside may pass to the outside. A velocity of about 6 feet per second is sufficient to produce this effect in a very short time. The Davy lamp is, therefore, not a safety-lamp in this current; nor would it be so if, while in this condition, it were subjected to a jerk or violent motion on the part of the person carrying it in a still explosive atmosphere. Another source of danger arises from the fact of inflammable material getting on the gauze. In a dry mine coal-dust adheres to it, and if gas should then be fired in the lamp the dust may be inflamed, and fire the explosive mixture outside. The same thing may occur from gauzes smeared with oil.

The Davy lamp consists of an iron wire gauze cylinder $1\frac{3}{4}$ or 2 inches in diameter, and 6 inches high, fixed to a brass ring, and screwed on to the oil-vessel. For better protection the gauze is doubled at its upper part. Outside the gauze 3 iron bars, placed at equal distances apart, connect the bottom and top rims, the latter having a metal roof, attached to which is a ring for carrying

the lamp. Through the oil-vessel, in a close-fitting tube, a wire called the pricker passes, the purpose of which is to trim the lamp, and draw down the wick when it is desired to extinguish the flame. Sometimes a shield of tin is placed round ⅔rds of the Davy lamp, it being fastened to two of the upright bars, on which it may be made to slide up and down. Besides its defectiveness in respect to passing the flame at a rather low velocity, another great objection to the Davy lamp is its insufficient light, and most of the more modern lamps give a better light, glass being introduced at the bottom instead of gauze for this purpose.

The oldest form of glass lamp is the *Clanny*. It consists of a lower cylinder of stout glass surrounding the flame, and an upper cylinder of wire gauze of less diameter. The feed air passes through the lower part of the wire-gauze cylinder, then down the inside of the glass cylinder, the products of combustion ascending inside the cold air-currents, and escaping through the upper part of the wire gauze. The oil-holder, with pricker, is the same as in the Davy lamp.

Morgan's is an excellent lamp. Its chief features are a double perforated air-shield, and the construction of a shield at the top of the lamp, through which the products of combustion pass. The air for feeding the flame, after passing through the perforations in the outer shield, goes through the perforations at the base of the inner chimneys, and so to the flame, the products of combustion passing through the cone-gauze in the interior of the lamp, and up through the top shield.

The *Protector* is also a good lamp. In it colzaline is burned instead of the vegetable oils used in other kinds of lamps described. It makes no smoke or soot, will not clog in the gauze, does not require any pricker, and very readily shows the presence of inflammable gas. Inside the Protector lamp-bottom is a sponge which, in trimming the lamp, simply requires to be saturated with oil, the superfluous colzaline being poured out again. A permanent wick, through which the oil is drawn up, extends to within about ⅓rd of an inch from the top of the tube, the remaining portion of the tube being filled up by asbestos. The illuminating power of the lamp is excellent. This system of lighting is applied to many other lamps besides the Protector lamp, which term (Protector) refers more to the mode of locking than to the lamp itself. Its peculiarity consists in the fact that, when a lamp has been locked, it cannot be opened without putting out the light. There is not much advantage in this, however, for if a person were likely to open a safety-lamp at all where this ought not to be done, he is also likely to carry matches, so as to re-light the wick.

The *Pieler* lamp, shown in Fig. 378, is used solely for examining the air in a mine. When first invented it was intended only to use this lamp in the laboratory to test samples of air brought out of the mine. It has the usual vessel, G, to hold the burning medium, which in this case is pure alcohol, C_2H_6O. To prevent the escape of vapour of alcohol the lamp is very carefully constructed. The reservoir containing the spirit becomes heated when the lamp is in use, and produces large volumes of spirit-vapour, which, on attaining a sufficient pressure, may force the alcohol up the tube in the form of spray, more especially if the wick-tube extends downwards to reach nearly to the bottom of the reservoir. To provide against this the reservoir must not be charged beyond a certain height, and in addition, the wick-tube and the tube which surrounds it above the surface of the alcohol are pierced by small holes, through which the vapour, as it is formed, escapes, to be consumed in the flame. A cylindrical wick, E, is used. It is made of silk, and passed over a tube, F, provided with a small nut inside. Upward or downward motion is given to the wick by means of the screw, D. A short conical chimney, C, open at the top and base, is attached for protecting the

eye of the observer. Care must be taken to adjust the lamp-flame, so that its upper extremity is exactly on a level with the upper edge of the chimney. A gauze, B, similar to the Davy lamp, but of unusual length, is used. The object of the long gauze is to allow the cap to develop itself more freely inside when the lamp is in an explosive mixture. The lamp is provided with the usual bars or pillars, A, for supporting the top. The spirit-chamber is made large enough for the lamp to burn while used for a prolonged journey through the workings.

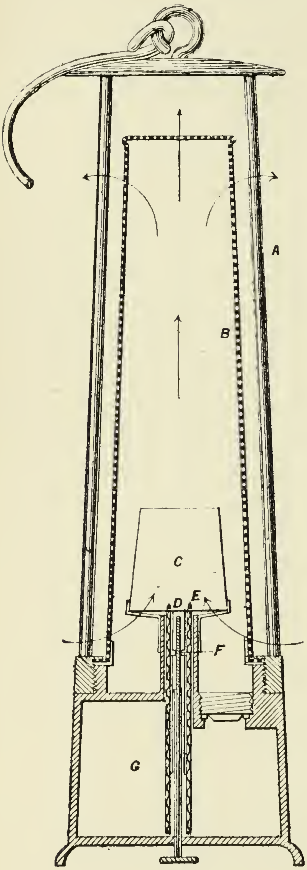


Fig. 378.—Pieler Lamp.

When the firedamp is mixed with the atmosphere in any proportion greater than $\frac{1}{4}$ per cent. its presence is detected by the Pieler lamp. The cone of light shown at the flame when in an explosive mixture is larger than that produced on the flame of any lamp using vegetable or animal oils. This sensitiveness renders it very valuable for some purposes.

According to experiments made :—

The cap with $\frac{1}{4}$ per cent. of firedamp is of a bluish-gray colour, and but slightly luminous; it has a height of $1\frac{1}{8}$ inches.

With $\frac{1}{2}$ per cent. the cap reaches 2 inches, is more sharply defined at the bottom, but fades away above.

With $\frac{3}{4}$ per cent. the cap reaches 3 inches, the edges are sharper, and the colour more blue.

With 1 per cent. the cap reaches $3\frac{1}{2}$ inches; edges more sharply defined; colour deeper blue.

With $1\frac{1}{4}$ per cent. the cap reaches 4 inches.

With $1\frac{1}{2}$ per cent. the cap reaches $4\frac{3}{4}$ inches.

With $1\frac{3}{4}$ per cent. the cap reaches the top of the lamp, the luminosity is increased in proportion, and the colour of the cap is deep blue.

With 2 per cent. the cap widens out at the top, and with higher percentages it continues to expand until the inner gauze is filled.

The lamp is thus described in the Report of the Royal Commission on Accidents in Mines, 1886 :—

"Pieler's is a large Davy lamp, constructed to burn alcohol with an argand wick. The air supplied to the inner part of the flame is admitted by a tube, protected by superposed discs of gauze, which passes vertically through the vessel containing the alcohol. Around the flame is a short, conical chimney, open above and below, and the flame is so regulated that it does not appear above the chimney, its height being, therefore, from 1 to 1·25 inch. In gas this spirit-flame yields a much more conspicuous cap than can be produced by the flame of ordinary vegetable or animal oil. . . . The Pieler lamp is obviously a most sensitive gas-detector, but in its present form it is quite inadmissible for use in well-ventilated mines, for the following reasons. The flame is easily extinguished by a very moderate current, and if the lamp happens to come into an explosive mixture of gas and air an explosion is almost certain to be caused in a few seconds. The lamp could be rendered less dangerous for general use by

enclosing it in a case, and, as far as we have been able to observe, its power of indicating the presence of gas would be but little if at all impaired."

Since these remarks were written the lamp has been improved, and in the form now used the flame is extinguished by the ignition of the gas.

Out of all the safety lamps experimented on by the Commissioners, only four were deemed worthy of recommendation by them as combining a high degree of security, with good illuminating power and simplicity of construction. These were Gray's, Marsaut's, the bonneted Mueseler, and Evan Thomas's modification of the bonneted Clanny lamp.

A drawing of *Gray's* lamp is shown in Fig. 379. In it the air reaches the flame by four tubes, down which it passes from near the top of the lamp as shown by the arrows in the drawing. The tubes terminate in a cylindrical chamber under the glass. The inner wall of the chamber consists of a strip of gauze and through this the air passes on its way from the chamber to feed the flame within the glass. The lamp gives a good light, the flame not being affected by oscillations of the lamp, nor by rough jerks in an upward or downward direction, and is considered to give considerable security in explosive currents. The principal defects pointed out by the Commissioners are (1) danger to the glass from heat produced by gas burning at the cylindrical strip of gauze immediately under it; (2) in currents of low velocity the ignited gas heats the lower edge of the glass strongly and in currents of high velocity a stream of ignited gas passes completely across the lamp from the windward side and plays on the glass on the opposite side, causing the glass to crack; (3) the top of the lamp may be easily tampered with; and (4) the gauze at the outlet is liable to be obstructed by soot if the flame should smoke.

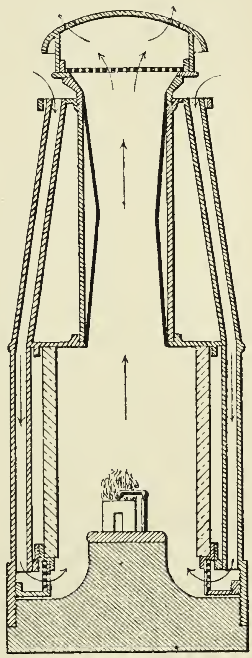


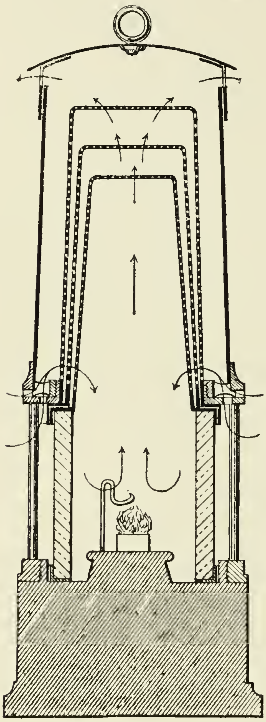
Fig. 379.—Gray Lamp.

The *Hepplewhite-Gray* is a slight modification of the Gray lamp just described. In it a flat wick is used as in the Gray, but two of the four tubes down which the supply air passes have openings in them close to their base. A suitably sized slide may be pushed up and down each of the tubes provided with openings, so as to cover them or leave them exposed to the surrounding air.

The cap at the top extremity of the lamp may be turned partially in a horizontal direction, and with it moves a plate which covers the upper ends of all four tubes at the same time, when the cap is turned in one direction, and leaves them free when turned in the other. By this means the supply air may pass from the surrounding atmosphere down the four tubes from the top, or, it may be shut off from admission there, and allowed to pass through two of the tubes at the bottom. This arrangement renders the lamp an excellent gas trier, as by closing the lower openings any explosive mixture near the roof or in holes above the roof is discovered, whilst in sluggish currents, the air may be admitted through the lower openings in the tubes. When both top and bottom openings in the tubes are closed at the same time, the supply air is shut off entirely, and the lamp goes out immediately afterwards. This may become necessary when testing for an

explosive mixture. The glass instead of being cylindrical in form is larger at the base, the top being the same size as the coned bonnet and gauze above it. A conical gauze cap is used in the Hepplewhite-Gray instead of the gauze diaphragm in the Gray shown at Fig. 379.

The *Marsaut* lamp is made with either two or three conical gauze caps. In Fig. 380 it is shown with three. It has a thick glass cylinder as in the Clanny lamp. The three gauze caps fit close together at their lower extremity on top of the glass, and gradually diverge from each other in proceeding upwards. The gauze caps are protected by a bonnet of sheet iron, screwed on a flange above



ig. 380.—Marsaut Lamp.

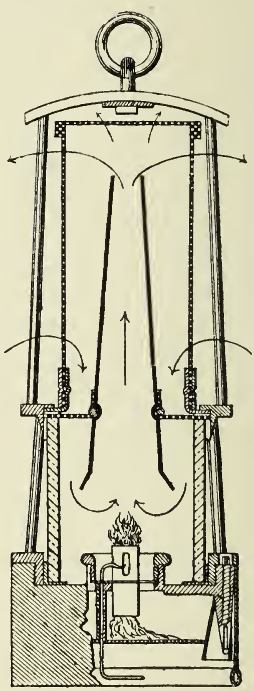


Fig. 381.—Mueseler Lamp.

the glass. Near the upper end of the bonnet is a gauze diaphragm, containing about 400 apertures to the square inch. Just above this diaphragm at the top of the bonnet and immediately below the top plate of the lamp, are a series of large holes through which the gases from combustion escape. Near the lower end of the bonnet are also a number of holes by means of which the feed air passes through the gauze caps immediately above the glass cylinder, and these openings are arranged so as to prevent the direct entry of horizontal currents of air into the lamp. No provision is made for preventing the removal of the bonnet. The gauze used in the caps has about 934 apertures to the square inch. In all other lamps the mesh of the gauze used is the same as that in the Davy lamp. A flat wick is used in the Marsaut lamp, which gives a better illuminating power than a round one. The lamp goes out in an explosive mixture. When used with two gauzes the lamp has an illuminating power of about two-thirds of a standard candle but with three gauzes the illuminating power is reduced to about one-half

of a standard candle. When used in an explosive mixture with only two gauzes, it is just possible for the flame to pass through the gauzes whilst the glass remains uninjured. When three gauzes are used the lamp is much safer, although the illuminating power is less. The lamp is liable to become much heated owing to the gases from combustion impinging on the bonnets which are in good metallic connection with other parts of the lamp. A considerable amount of heat is therefore conducted even to the bottom of the lamp when used where the air current is not sufficient to keep down the temperature. Other bonneted lamps become heated in the same way, but no objection can be urged against this so long as very volatile illuminants are not used.

The *Mueseler* lamp is constructed on a similar principle to the Clanny. It has a short cylinder of thick glass round the flame, above which is a gauze cap, Fig. 381. Immediately above the flame and extending within the gauze cap is a central conical metal chimney, the top of which in some forms of Mueseler lamp is covered with wire gauze, but in others is open at the top as well as bottom. The chimney is carried by an attached ring of gauze fixed to its outer circumference between the top of the glass cylinder and the bottom of the gauze cap.

The feed air, as indicated by the arrows in the drawing, passes first through the lower part of the gauze cap and then downwards through the horizontal gauze ring, continuing its course afterwards between the metal chimney and the glass cylinder. The inlet air has thus two obstructions to its passage, the outlet only one, if the chimney is not covered with gauze. The object of the chimney is to create a strong upward draught and to insure the inlet air being drawn down close to the inside of the glass cylinder and thus keep it cool. A great drawback is its liability for the light to go out if the lamp happens to be held with its axis at a slight angle to the perpendicular, as in that position the flame drives back the inlet air on one side and baffles the current. Fig. 381 shows the Mueseler lamp as made in Belgium, where it is constituted the legal lamp for use in fiery mines. The English made Mueseler lamps do not afford so much security as those made in the Belgian legal form.

The Commissioners say, "As a general rule, if a bonneted Mueseler is exposed to a current with any velocity we could obtain, the gas ignites under the horizontal gauze diaphragm, and is speedily extinguished. It may, however, continue to burn, and in that case, as the lamp is ordinarily constructed, the glass is almost certain to be cracked in a short time." Again, in their report, they give as the sources of danger and the disadvantages arising from the use of the Mueseler lamp: (1) the glass cylinder is easily cracked by a blow, by the flame playing directly upon it, or by the impact of cold water while in a heated condition; (2) there are difficulties to be overcome in maintaining at all temperatures sufficiently tight joints where the metal and glass parts meet; and (3) difficulties arising from combustion and a tendency to smoke the glass and impair the illuminating power.

Fig. 382 shows *Evan Thomas's* No. 7 lamp, of which the Commissioners speak very highly. In principle it is a Clanny lamp, but is bonneted and a great improvement on the ordinary Clanny form of lamp. Within the bonnet is a brass tube, one inch high, which fits the main gauze cylinder closely at its lower end. This tube terminates at its upper extremity in a horizontal brass flange, which extends nearly to the bonnet. Between the edge of the flange and the bonnet is an annular space one-sixteenth of an inch wide. The inlet air reaches this annular space after passing through horizontal slits in the bonnet near its lower end. The feed air in continuing its course passes through the main gauze cylinder immediately above the brass tube and descends to the flame. The products of

combustion escape through holes near the top of the bonnet which are protected by a shield secured to the bonnet. The main gauze cylinder is protected by a gauze cap closely fitting it.

The Commissioners say:—" No. 7 seems to be a most efficient lamp. The flame is bright and remarkably steady in the strongest air current we can produce. In an explosive atmosphere, moving with a velocity of 3,200 feet per minute, it showed no signs of danger after an exposure of seven minutes and forty seconds. The gas continued to burn in the gauze cap, and a portion of the gauze quickly became red hot, but its temperature appeared to be considerably below that required to ignite the gas mixture. With current velocities down to 400 feet per minute the gas always burned continuously in the gauze, but the latter did not become visibly hot until the velocity approached 1,600 feet per minute. The lamp flame was in all cases extinguished in the gas mixture in a few seconds."

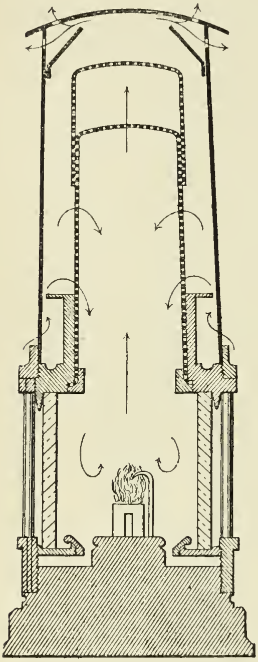


Fig. 382.—Evan Thomas's Lamp

Again, " In this lamp the quality of safety, in a pre-eminent degree, is combined with simplicity of construction and with illuminating power at least fully equal to that of any of the lamps hitherto in general use, and there is no probability of the flame being extinguished under any circumstances attending ordinary use."

In another section of the Commissioners' Report appear the following remarks:—" This lamp seems very safe in all currents in which it was tested. In air moving with any velocity up to 3,500 feet per minute the flame burns very steadily when the lamp is either erect or inclined. The flame is scarcely affected by violent oscillations of the lamp or by rapid motion up and down in a vertical direction, and it is not extinguished by inclining the lamp until the latter is nearly horizontal."

The *Clifford* lamp, as shown in Figs. 383—385, is new since the publication of the Commissioners' Report, it having only recently been patented. It is to be called the Phœnix lamp, is novel in construction, and is designed to give great resistance to the passage of flame in high current velocities. In its construction, the usual form of having a glass cylinder surmounted by a cylindrical gauze has been entirely departed from.

Fig. 383 is a vertical section; Fig. 384 a transverse section on the line A B; and Fig. 385 is a plan of the oil chamber and attachments with the upper portion of the lamp removed. The glass cylinder surrounding the flame is firmly held in position by asbestos washers. The upper portion is contracted in diameter and is covered by a metal hood, which forms part of a segmental pillar or box, K, cast in one with the base portion P, or attached to it in any other reliable and substantial manner. The base is fitted tightly against the oil chamber by means of the shackle hinges U and T, which are of special construction, and jointed in a thoroughly safe way. The gauze E is a strip bent to fit the segmental portion (Fig. 384) of the box pillar K, and protected by three bonnets, J, G, F. The main bonnet J hinges at C to the pillar portion K, and, when unhinged, access to the gauze is obtained for the purpose of inspection and cleaning as required.

The gauze is forced between the segmental surfaces of the bonnet and the

pillar K. The shackle U has an inclined face, which is made to press against the projecting inclined piece or wedge N, so that when closed by hinging from R, the portion M of the bonnet will be firmly pressed against the gauze to make a joint. The gauze may be secured to the segmentary edges of the box K in many ways, any of which renders it easily got at for inspection. After the yoke T is slipped over S, it may be strained up by screw or fastened with a lead rivet.

The air supply enters the bonnet J at the passage L, which is protected by the metal plate F so as to prevent direct entry, and passes on through the space

VERTICAL SECTION

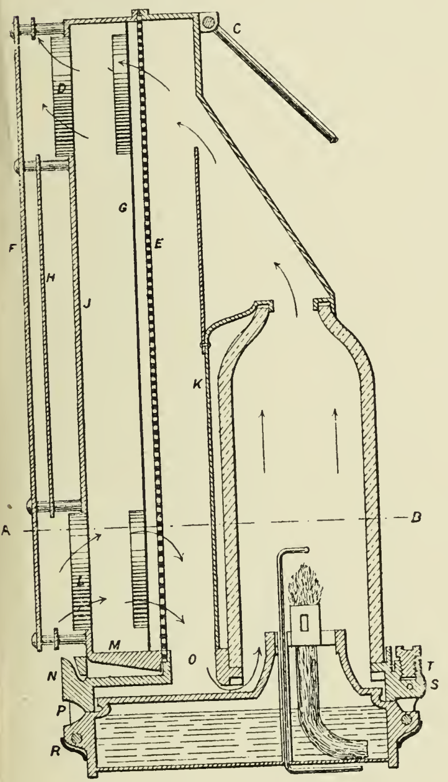


Fig. 383

TRANSVERSE SECTION ON LINE A.B

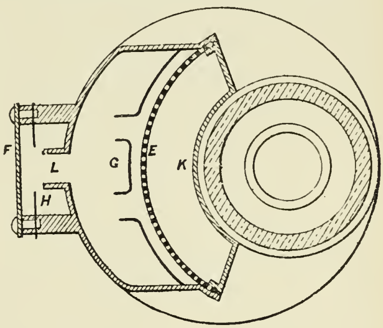


Fig. 384.

PLAN OF OIL CHAMBER AND ATTACHMENT

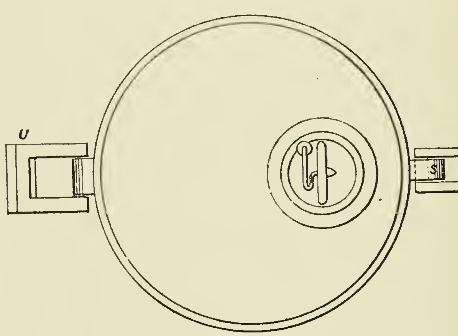


Fig. 385.

THE CLIFFORD LAMP.

formed between the bonnet J and shield G. It reaches the gauze E through the two apertures in the internal shield G which are opposite to L, but not in direct line with it. The air then descends into the space O and passes under the glass by the annular space shown, continuing its flow upwards to the flame. The hot products of combustion then ascend and pass out of the glass cylinder and reach the upper portion of the space enclosed between the gauze E and the pillar K through the hood. The outward flow is continued, as shown by the arrows, through apertures in the shield G and the passage D in the bonnet J, which is protected similarly to the air inlets.

It is claimed for this lamp that in it the light from the flame is free to strike

upwards with but little obstruction above, and whilst the advantage of air supply from below the flame is obtained, the gauze is not placed under the wick, and thus risk of clogging it by spilling the oil is avoided. The light given is good, as a plentiful supply of air enters the lamp and the light illuminates the roof as well as the sides of the workings. It is not sensitive to tilting or violent movement. The bonnet arrangements prevent the possibility of a current of any velocity from impinging directly upon the gauze, and thereby renders the lamp safe in explosive currents. It is said that the lamp has withstood an exceptionally high velocity test.

It is too early to form an opinion of this lamp, as it must be practically used for some time in order to thoroughly test it; but judging from the drawings it does not appear perfect in construction. The shoulder formed on the glass cylinder where it is reduced in size is not covered by the hood, and although this may to some extent allow the light to strike upwards, it leaves the glass exposed to falling stones or coal from the roof or sides, a small piece of which is sufficient to fracture it. No upright bars or pillars are placed for protecting the glass cylinder, which renders it less secure on that account, and in wet places the lamp would be very liable to be cracked by water dropping on it.

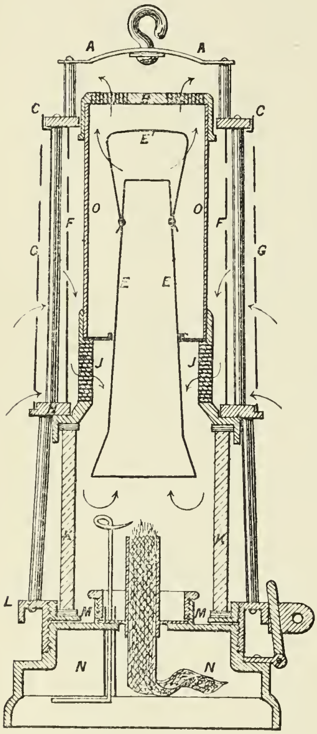


Fig. 386.—McKinless's Gauzeless Safety-lamp.

McKinless's gauzeless safety-lamp, shown in Fig. 386, is another novelty in construction, and, like the Clifford lamp last described, is new since the publication of the Royal Commission's Report on Accidents in Mines.

The most striking feature of this lamp is that gauze is entirely discarded in its construction.

The supply air is admitted through a large number of very small holes drilled in a belt or band, J, above the glass cylinder K and middle ring of the lamp H, and after passing downwards between this belt and an inner conical chimney, E, reaches the combustion chamber. At the top of the conical chimney E is fixed a cap, E′, to collect the unconsumed particles of carbon or soot.

The products of combustion pass upwards through the conical chimney and cap, and thence through a large number of very small holes drilled in a cap, B, and escape near the top of the lamp.

The outlet cap B is fitted and riveted to a cylindrical tube O, the lower end of which fits into a collar of the supply air belt J, on which collar the diaphragm of the conical chimney rests. This diaphragm separates the inlet and outlet currents, and renders certain the passage of the feed air into the combustion chamber. An upper ring, C, is placed level with the top of the bonnet, through which the outlet cap is visible. The products of combustion thus escape without re-mixing with the supply air.

The feed air belt J is protected by two shields, G and F, which are placed outside it. The shields have large openings to allow the free ingress of air. The

arrangement of these openings prevents the force of a current from striking directly against the small feed air holes and so disturbing the flame. The outer shield is easily removed when damaged, and after being repaired can as easily be re-fixed, being fastened by simply turning in four or five tongues of its own metal under the upper ring C. The combustion chamber and the drilled belt J are kept securely in their place by the ring H; L is the bottom ring which secures the whole to the oil chamber N; K is the glass cylinder, and M a ring for holding the glass in its position. The metal in the belt J and in the outlet cap B is $\frac{1}{8}$th of an inch thick, and each hole is therefore $\frac{1}{8}$th of an inch long and $\frac{1}{26}$th inch diameter. The three lower rows of openings in the outer shield G may be covered with asbestos cloth or leather, and the supply air then enters at the top of the lamp; thus used it is an excellent gas tester. The lamp weighs 3 lbs. It is stated that it is not sensitive to tilting, swinging, or jerking, and that it has been tested in explosive mixtures of high velocity without the outer gas being fired.

This lamp requires to be used for some time before forming a decided opinion about it; it should, however, be remarked that the gauze is not the only weak part of a safety-lamp.

In all oil safety-lamps using a glass cylinder, there is a possibility of the glass becoming cracked, or injured. This may be done by a blow, by carelessly holding the lamp out of its erect position so as to allow the flame to play directly on the glass, or by cold water coming into contact with the glass when the latter is more or less heated.

The cost of oil and wick for safety-lamps is about one halfpenny per lamp per shift of eight hours, but the cost varies with circumstances.

All safety-lamps have locks to them, a frequent form of lock being a simple bolt and lead plug, which prevents the oil-vessel from being unscrewed. The "Cryptograph" is an ingenious lock, designed to give security by preventing the miner from tampering with his lamp, while it may be readily opened by a qualified and appointed person. The lock is based on the Permutation lock, and is capable of many thousand changes, rendering the chances of opening it, without the knowledge of the sequence of the symbols, practically impossible.

Cuvelier's patent lock for miners' safety-lamps is very ingenious in construction. The following are the particulars of it as supplied by Messrs. W. P. Thompson & Co., Patent Agents, Manchester:—

The invention is designed to absolutely prevent the opening of the lamp by any unauthorised person, or in any but the proper place.

It is an undoubted fact that the lamps at present in use are opened by the miners, notwithstanding the seals and screws by which they are fastened.

The lock invented by Mr. Cuvelier is exceedingly simple, and most effectual in preventing the opening of lamps in the workings. It consists of a ring opened and closed by the force or pressure of a liquid acting upon it internally, which causes it to contract and expand on exactly the same principle as that adopted in the Bourdon pressure-gauge, so largely used.*

The bolt of the lamp consists of a metal rod, A, formed with a shoulder, B (Figs. 387–390). It is placed in a chamber, C, at the side of the oil reservoir, R, and pressed back by a wire spring, D. Below the reservoir is placed the lock, N, comprised of the tube, E, hermetically sealed at the ends by the solid end-

* The principle of the Bourdon tubes is fully described in Chapter XIV., under the head of "Pressure and Vacuum Gauges."

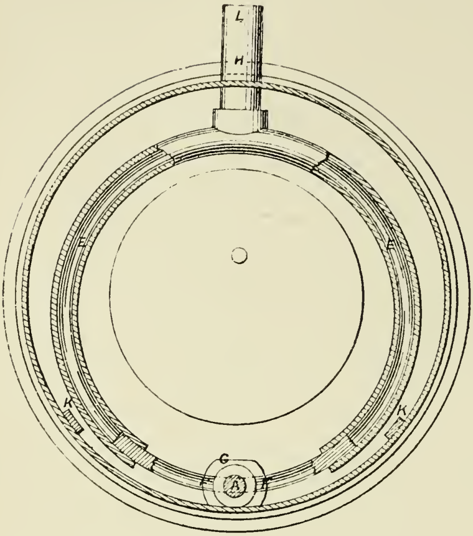


Fig. 387.

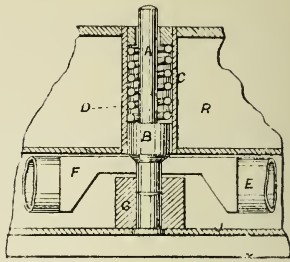


Fig. 388.

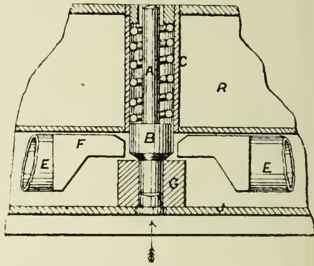


Fig. 389.

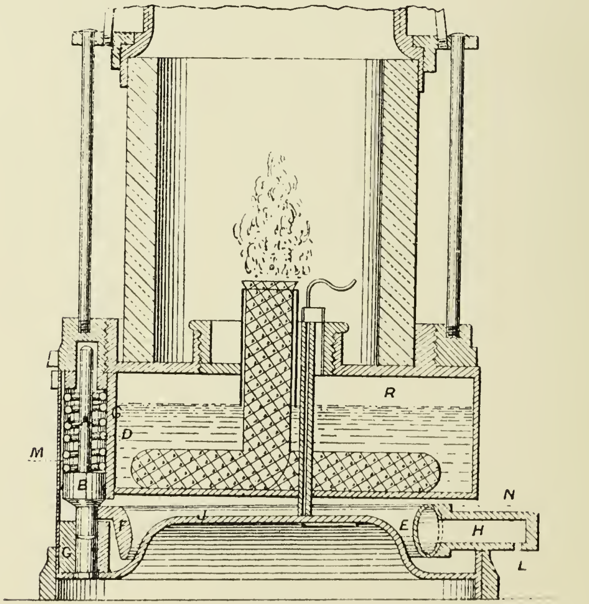


Fig. 390.
Cuvelier's Lock for Safety-Lamps.

pieces, F, and the inlet-pipe, H, with a small pin-hole, L, at the bottom. The ends, F, when closed, rest below the shoulder, B, and lock the bolt. To open the lamp, water is forced into the tube, E, through the hole, L, by means of a

pump or accumulator (placed in the lamp-room), which expands the tube, drawing the ends, F, clear of the shoulder, B, which is then shot down past them by the spring, D. The elastic pressure of the tube draws the ends together again, under the shoulder, B, as soon as the bolt is pushed up, by means of a wire, introduced into an orifice in G (Fig. 389), as shown by the arrow, to again lock the lamp. No special appliance is needed for locking the lamp. A plate or false bottom, J, is soldered in below the tube, to keep it safe, and prevent it from being tampered with. This lock can be fitted to any ordinary lamp.

M Lamp Casing.
N Lock.
R Oil Reservoir.
A Bolt.
B Shoulder on bolt. A.
C Casing of bolt.
D Spring.
E Ring forming lock.
F Solid end of lock-ring.
H Inlet-pipe to lock-ring.
L Orifice in pipe, H.
J Plate to protect tube.
K Stop-pieces to prevent undue expansion of tube.

Fig. 387 is a plan (looking from below). Fig. 388 is a sectional view showing the position of the bolt, A, when the lamp is locked. Fig. 389 is a sectional view showing the position of the bolt when the lamp is unlocked; and Fig. 390 is a sectional view showing the lower part of a safety-lamp with the lock applied to it.

There are dangers in working with even the safest form of oil safety-lamps, as it is impossible to prevent risk of the glass cracking or breaking. Without going so far as to say the highest possible point of safety has been reached in the design of the oil-lamp, it is in the direction of portable electric safety-lamps the miner must look for any marked improvement or great degree of safety. Inventors are actively engaged on this form of lamp, which will probably be adopted in the future when their work is completed.

In the meantime the oil lamp must be used with becoming caution, and in full recognition of its defects.

Modern lamps are more complicated in their construction than the first type, and the number in use is vastly increased. The work of examining these lamps at large collieries is, consequently, considerable. In many cases the lamp is half covered with a bonnet, hiding from the attendant's view the most important parts. The large number which must be taken to pieces before they can be examined, and afterwards restored to working condition, entails much labour, and it is possible that some small but important part may be omitted in the operation. It is very difficult for the eye to detect defects in the adjustment, and impossible —without resorting to other means—to know whether the joints between the glass cylinder and the gauze are perfect under the varying temperatures at which a lamp is worked. If a thoroughly reliable and simple means of testing could be devised, it would be well to test each lamp before it is taken into the pit. At some collieries this is done daily in the lamp-room by placing the lamp (lighted), after examination, in a mixture of gas and air previously ascertained to be a properly explosive one. This test should be slow and deliberate, and the lamp allowed to remain some time in the mixture.

The Royal Commissioners draw particular attention to this point. They say, "With the safer and more complicated lamps it is still more difficult to detect by eye defects in adjustment. Indeed, in many instances important parts cannot

be seen after the lamp has been put together. During the course of our experiments explosions have been occasionally traced to imperfections so small that we have had some trouble in finding them even when certain of their existence. Experiments 723–725 of the Woolwich series are examples of this, as will be seen by comparison with those following them. We consider it, therefore, absolutely necessary that such lamps should be regularly tested in an explosive gas mixture before they are allowed to descend the shaft." In another part of their report:—"A lamp may be of the safest pattern, and yet small defects in the fitting of its parts may entirely deprive it of its power of affording protection. In preparing a large number of lamps for use in a mine it may happen even with the greatest care on the part of the lamp-man that a lamp in an imperfect condition may be allowed to pass. The detection of these imperfections by simple inspection is in many cases almost impossible. And we are convinced that the only way of avoiding the introduction into a mine of a dangerously imperfect lamp is to test every lamp in an explosive mixture of air and some inflammable gas before it is allowed to descend the shaft."

Mr. Patterson, of Newcastle-on-Tyne, has patented an apparatus for the supply of explosive mixture to a safety-lamp. The mixture (which should be of uniform nature) is conveyed through an upright pipe provided with a tap for regulating the supply, and discharged through the casing at the centre of a small fan driven by means of a belt from the fly-wheel of an engine. The fan outlet is connected with the test-box by a short horizontal pipe. The box rests on a table of suitable size, and has a hinged cover through which the lighted lamps are passed, and allowed to rest on the bottom of the box. A window is fixed in one side of it, through which the lamp-man watches the lamp he is testing at the same time that he keeps one hand resting on the handle of the supply-tap, so that he can watch the lamp, and regulate the amount of explosive mixture at the same time. In this way the mixture is forced round the lamp in every part, and defects detected.

Safety-lamps provided with the best form of lock to prevent their being tampered with by ignorant or reckless workmen at the face, and tested thoroughly before given out, will, if carefully used, afford considerable protection in the mine. At convenient places near the working faces there should be recognised depôts for keeping reserves of locked lighted lamps ready for use. On a workman's lamp becoming extinguished another in working condition is thus available within easy distance of him. It is the practice at many collieries to keep boys for the purpose of travelling from the lamp-stations in the mine to the innermost roadways, carrying with them lighted locked safety-lamps, which they give to the workmen whose lamps have become extinguished during their work, and receive the extinguished lamps in return. When all the lighted lamps are distributed the boys return with those they have collected from the workmen to the lamp depôts, where they exchange them for more reserve lamps to be carried "in bye" again. These arrangements tend to the comfort of the workmen at the face, and give some little security against their tampering with the lamps. For these reasons they are to be commended.

Portable *Electric Safety-Lamps* have now become an established fact, and are in use at some collieries. They are what are called incandescent lamps. Incandescent lamps are simply small glass bulbs, containing a carbon filament, the ends of which are attached to two thin platinum wires, which pass through the glass, and conduct the electric current to and from the carbon filament. Wherever electrical energy is produced and passed through a conductor, it is deprived of energy, which is not destroyed or lost, but appears in the form of heat in the conductor. The amount of heat produced in the conductor is equal to the electrical energy not otherwise accounted for, or missing as such, at the end of the conductor, and that amount varies in accordance with the resistance offered by

any conductor to the passage of an electric current. The current for an incandescent lamp is conveyed in by one wire, then through the carbon filament, and out by the other wire. The circuit is continuous, and the electric current in its passage meets resistance in the carbon filament, in overcoming which the electric current displays itself by generating its equivalent in heat, thus rendering the carbon incandescent. This white heat is produced in a vacuum, as every particle of air is pumped out of the small glass bulb containing the carbon filament before being hermetically sealed. There is no flame and no combustion in the incandescent light.

Platinum wires are used in preference to those made of other metals, because platinum comes closest to glass in its co-efficient for expansion by heat. If wires of copper, iron or silver were used, the probability is that the greater expansion by heat of these metals than glass, would cause the latter to burst or break, or, at any rate, prevent the possibility of retaining a good vacuum.

Another form of the electric light is known as the arc light. It is not suitable for underground use, as it requires a large electric current and a high electromotive force, but it is sometimes used at the pit bank. In the electric arc lamp the conducting wires are attached to two rather thick sticks of carbon, the ends of which are kept a short distance apart, so that there is a break in the continuity of the electric current. As the current leaps across the space between the two carbon sticks, a brilliant flame is produced, and the carbon sticks burn away.

The different forms of portable electric safety-lamps arise from the kind of battery used to supply the necessary current, the carbon filament in the glass globe being common to the different lamps. In all, the battery must be attached in a portable form, so that as the lamp is carried in the hand from place to place the battery may supply the electricity for a specified length of time. Portable batteries are either primary or secondary. In the former, electric energy is produced when zinc in the presence of another element is acted upon by a chemical compound, and is replenished by putting fresh plates and fresh chemicals into it. In the latter the energy is derived from some extraneous electric generator, and is stored in the battery at intervals.

The chief drawback to primary batteries is, that they are expensive to maintain, on account of the materials they consume. The objection to the secondary batteries is, the necessity of having another apparatus—a dynamo—to re-charge them.

Theoretically, whatever may be the form of battery, the lamp may be made to give any amount of light for 10, 12, or more hours, as may be desired, but, practically, the amount of light is limited by the weight it is convenient to carry.

The light is quite independent of the surrounding atmosphere, and it will burn equally well in any form of gas, which will not be affected by the light unless the glass globe be broken. On the glass breaking the lamp is almost instantaneously extinguished. It is plain, therefore, that no explosion can result from the use of the electric lamp unless the glass which surrounds the light be first broken, and the lamp at that instant happens to be in an inflammable atmosphere.

For surveying with the magnetic needle this lamp is not applicable, but for all other purposes it is unquestionably a great boon. As it is impossible to test for gas with the electric safety-lamp, a suitable fire-damp detector must be placed with it, in the hands of a fireman, or be used by any one wishing to ascertain if fire-damp be present in the mine. Liveing's, Swan's, or Lewis & Maurice's, or any other reliable fire-damp indicators, may be used.

Electric portable safety-lamps are in their infancy, and, although in practical use, they do not at present compare favourably in point of first cost or in maintenance with the best oil lamps, the latter costing only about one-half of the

former to maintain throughout a shift. Possibly colliery proprietors who supply lamps for the use of their workmen are awaiting further inventions, and the survival of the fittest before adopting it to any extent.

FIRE-DAMP DETECTORS.

The *Pieler* lamp, which has been fully described in this chapter, is a very useful and practical fire-damp detector. In many forms of detectors samples of the gases are procured in the mines, to be afterwards examined.

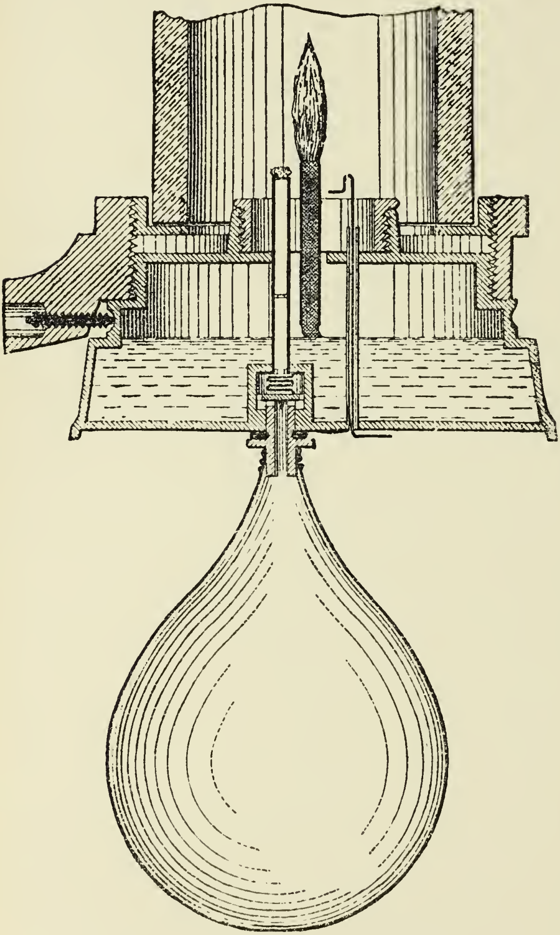


Fig. 391.—Garforth's Firedamp Detector.

Garforth's detector is one of this kind, and is very simple in construction. The following description of it is taken from the *Colliery Guardian* of August 15th, 1884:—

"Mr. Garforth's invention is extremely simple. It consists in the use of a small india-rubber hand-ball, without a valve of any description, Fig. 391, but by the ordinary action of compressing the ball, and then allowing it to expand, a sample of the suspected atmosphere is drawn from the roof or any part of the mine, without the great risk which now attends the operation of testing for gas, should the gauze be defective. The sample thus obtained is then forced through a small protected tube on to the flame of the lamp, when, if gas is present, it is shown by the well-known blue cap and elongated flame. From this description, and from the fact that the ball is so small that it can be carried in the pocket, it will be apparent what a valuable adjunct Mr. Garforth's invention will prove to the safety-lamp.

"The following extracts are taken from a paper recently read before the *Midland Institute* :—

"Out of twenty-eight tests made in a mine working a longwall face, the Davy showed gas only eleven times, whilst the detector showed it in every case. The detector, as will be perceived from the one exhibited, and the accompanying sectional drawing (Fig. 391), consists simply of an oval-shaped india-rubber ball,

fitted with a mouthpiece. The diameter is about $2\frac{1}{4}$ inches by 3 inches; it weighs 2 ozs.; and it is so small that it can be carried without inconvenience in the coat, or even waistcoat, pocket. Its capacity is such that all the air within it may be expelled by the compression of one hand. The mouthpiece is made to fit a tube in the bottom of the lamp, and when pressed against the india-rubber ring on the ball-flange, a perfectly tight joint is made, which prevents the admission of any external air. The tube in the bottom of the lamp is carried within a short distance of the height of the wick-holder. It is covered at the upper end with gauze, besides being fitted with other thicknesses of gauze at certain distances within the tube; and if it be found desirable to further protect the flame against strong currents of air, a small valve can be placed at the inlet, as shown in the drawing. This valve is made of sufficient weight to resist the force of a strong current, and is only lifted from its seat by the pressure of the hand on the mouthpiece. It will be apparent from the small size and elasticity of the detector that the test can easily be made with one hand, and when the ball is allowed to expand a vacuum is formed within it, and a sample of the atmosphere drawn from the breaks, cavities, or highest part of the roof, or, of course, any portion of the mine.

"When the sample is forced through the tube near the flame, gas, if present, at once reveals itself by the elongation of the flame in the usual way, at the same time giving an additional proof by burning with a blue flame on the top of the test-tube. If gas is not present, the distinction is easily seen by the flame keeping the same size, but burning with somewhat greater brightness, owing to the increased quantity of oxygen forced upon it.

"I venture to claim for this method of detecting fire-damp the following amongst other advantages:—(1) The detector, on account of its size, can be placed in a break in the roof where an ordinary lamp—even a small Davy—could not be put; and a purer sample of the suspected atmosphere is obtained than would be the case even a few inches below the level of the roof. (2) The obtaining and testing a sample in the manner above described takes away the possibility of an explosion, which might be the result if a lamp with a defective gauze were placed in an explosive atmosphere. No one knows how many explosions have not been caused by the fire-trier himself. This will now be avoided. (Although lamps with a tin shield will be subjected to the same strict examination as hitherto, still they do not admit of the same frequent inspection as those without shields, for in the latter case each workman can examine his own lamp as an extra precaution, whereas the examination of the tin-shield lamps will rest entirely with the lampman). (3) The lamp can be kept in a pure atmosphere, whilst the sample is obtained by the detector, and at a greater height than the flame in a safety-lamp could be properly distinguished. The test can afterwards be made in a safe place at some distance from the explosive atmosphere, and owing to the vacuum formed, the ball (without closing the mouthpiece) has been carried a mile or more without the gas escaping. (4) The detector supplies a better knowledge of the condition of the working places, especially in breaks and cavities in the roof, which latter, with the help of a nozzle and staff, may be reached to a height of 10 feet or more by the detector being pressed against the roof or sides, or by the use of a special form of detector. (5) Being able at will to force the contents of the detector on to the flame, the effects of an explosion inside the lamp need not be feared. (This danger being removed, admits, I think, of the glass cylinder being made of a larger diameter, whereby a better light is obtained; it may also be considered quite as strong, when used with the detector, as a lamp of a small diameter when the latter is placed in an explosive atmosphere.) (6) The use of the detector will permit the further protection of the present tin-shield lamp, by an extra thickness of gauze if such addition is found advantageous in resisting an increased velocity. (7) In the

Mueseler, Stephenson, and other lamps, where the flame is surrounded by glass, there is no means of using the wire for shot-firing. The detector tube, although protected by two thicknesses of gauze, admits of this being done, by the use of a special form of valve turned by the mouthpiece of the detector. (The system of firing shots or using open lamps in the same pit where safety-lamps are used is exceedingly objectionable ; still, under certain conditions, shots may be fired without danger. Whether safety-lamps or candles are used, it is thought the use of the detector will afford such a ready means of testing that more examinations will be made before firing a shot, thereby ensuring greater safety.) (8) In testing for gas with a safety-lamp, there is a fear of the light being extinguished, when the lamp is suddenly placed in a quantity of gas, or in endeavouring to get a very small light; this is especially the case with some kinds of lamps. With the detector this is avoided, as a large flame can be used, which is considered by some a preferable means of testing for small quantities, and the test can be made without risk. Where gas is present in large quantities, the blue flame at the end of the test-tube will be found a further proof. This latter result is produced by the slightest compression of the ball. (I need not point out the inconvenience and loss of time in having to travel a mile or more to re-light.)

"As regards the use of the detector with open lights several of the foregoing advantages or modifications of them will apply. Instead of having to use the safety-lamp as at present, it is thought that the working place will be more frequently examined, for a sample of the suspected atmosphere can be carried to a safe place, and forced on to the naked light, when if gas be present it simply burns at the end of the mouthpiece like an ordinary gas jet. There are other advantages, such as examining the return airways without exposing the lamp, &c., which will be apparent, and become of more or less importance, according to the conditions under which the tests are made. In conclusion, I wish to point out that the practice adopted at some collieries of having all the men supplied with the most approved lamp (such as the Mueseler or the tin-shield lamp) except the deputies (who are supplied with the Davy), is not a safe one. If the strength of a chain is only equal to the weakest link, it may be argued that the safety of a mine is only equal to that of the most careless man or most unsafe lamp in it. If therefore the deputies, whose duty it is to look for gas and travel the most dangerous parts of the mine are obliged to use the Davy on account of its sensitiveness, may it not be said, that as their lamps are exposed equally with the workmen's to the high velocities of air, that they are the weak links in the safety of the mine. For the reasons given, I venture to submit that the difficulties and dangers I have mentioned will be largely reduced, if not wholly overcome, by the use of the fire-damp detector."

The Royal Commissioners thus speak of Mr. Garforth's invention :—

"For extracting the gas from crevices Mr. Garforth uses a small hollow india-rubber ball provided with a metal nozzle. The ball being compressed in the hand so as to expel the greater part of the air contained in it, the nozzle is inserted into the crevice or cavity and the ball is then allowed to expand to its natural size. It of course becomes filled with the gas mixture existing in the place under examination, and this gas may be introduced into a safety-lamp through a gauze-protected channel by again compressing the ball. For thus testing the gas a bonneted lamp is used, through the oil cup of which passes, close to the wick tube, a narrow pipe containing gauze diaphragms, and terminating below in a tube which just fits the nozzle of the india-rubber ball. The external end of this tube is closed by a spring valve, and when the nozzle is introduced it opens the valve and the gas can be forced up the pipe and on to the lamp flame. This simple and extremely portable apparatus seems to answer its purpose perfectly, and the addition to the lamp of the pipe above-mentioned does not affect either its security or its illuminating power."

By the aid of *Liveing's* firedamp detector,* very small quantities of gas in the underground workings may be detected. It is shown at Figs. 392–395 and consists of a brass tube about eight inches long by one-and-three-quarters inches diameter, closed at the ends by discs of hard wood. Through these discs are passed the insulated connection wires. At G and P these wires carry fine platinum spirals, the one at P being enclosed in a glass tube R, and that at G being exposed to the air within the instrument. Between the platinum spirals is supported a small wedge-shaped screen C by means of an arm F. The two surfaces of this screen are covered with white paper and can be seen through the glass disc J in the side tube H, to which the arm and screen are attached.

By means of a battery worked by hand, an electric current is passed as shown by the arrows till the spirals attain a red heat. One side of the screen C is illumined by the covered wire P, the other by the working wire G, the wires themselves being hidden from view whilst the instrument is in use.

On passing the electric current under ordinary conditions of the air inside the instrument, the two surfaces of the screen C appear equally illuminated on being viewed through the glass disc J; but if inflammable gas is present that side of the screen which is opposed to the working wire G appears brighter than the other. To measure this inequality of brightness, the screen C is moved towards the covered wire P, the movement being effected by sliding the side tube H in that direction. After the screen is so adjusted as to make its two surfaces appear equally illuminated, the amount of movement given the side tube is made to read a graduated scale showing the corresponding per centage of gas present in the air from $\frac{1}{4}$ to 4 as marked on the drawing, Fig. 392. An index is fixed to the outer tube N by means of which the per centage is read. The side tube H which carries the arm F and screen C, is screwed into the outer tube N of the instrument and a slot is cut in the body of the instrument to allow the necessary travel for the side tube H towards the covered wire P. In no position of the

Scale ½ full size

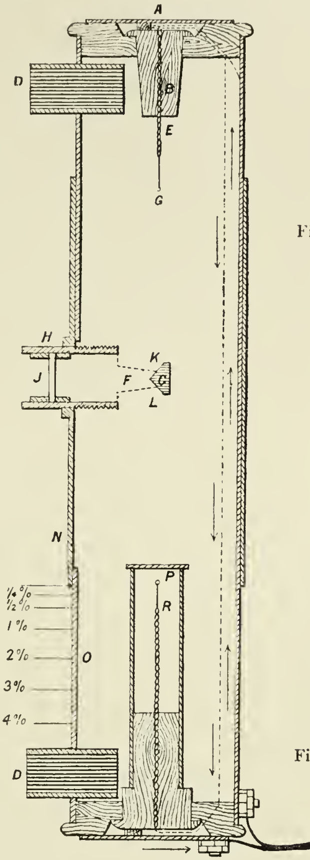


Fig. 393.

Fig. 394.

Fig. 392.

ENLARGED VIEW OF THE SCREEN C & SIDE TUBE F

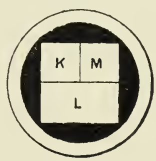


Fig. 395.

LIVEING'S FIREDAMP DETECTOR.

* See Transactions, North of England Institute of Mining Engineers, vol. xxviii., pp. 167—170.

screen is the slot in the instrument uncovered. D D are two Hemmings jets, which admit of the air being drawn into the instrument for examination through bundles of iron or copper wire in the tubes. This is effected by placing the mouth of the observer over the lower orifice and drawing in a breath. The outer air then enters the instrument. The platinum spirals are heated red by passing the electric current and the photometer (light-measurer) is adjusted by the sliding movement given it if inflammable gas is present. When two or three per cent. of gas is in the mixture the difference in colour of the light causes some difficulty in judging correctly the precise position of the screen. To overcome this difficulty, one half M, Fig. 395, of the side of the screen next G is covered with yellowish red paper, the other half K being left white. For quantities up to 1 per cent. K is compared with L, but in larger quantities M is employed instead of K, as its tint resulting from the yellow surface neutralizes the very white light given by the working wire G and gives facility for accurately judging the position of the photometer. In case of an explosion inside the instrument it cannot be communicated to the outside, as the hot gases become cooled in passing through the bundle of iron or copper wires in each of the entrance tubes.

Lewis and Maurice's fire-damp indicator (the invention of Sir William Thomas Lewis and Mr. A. H. Maurice) is shown in Figs. 396–399.* E is an air chamber, containing about 2 cubic inches of air; in it the mixture of gas and air to be tested is burned. A gauge J has an ivory scale attached to its upper limit F, graduated to read to $\frac{1}{4}$ per cent. of firedamp. A light brass shield H protects the upper limbs F G of the gauge. The bottom of the air chamber consists of a brass cap, fitted with a leather washer, to ensure its screwing on quite air-tight. The bottom of the air chamber is shown unscrewed in the sectional elevation at Fig. 396, but screwed on in the side elevation in Fig. 397. It is removed to admit of the entrance of the sample air to be tested. K is a platinum wire $\frac{3}{4}$ of an inch in length and of a size suitable to offer such resistance to the electric current passing through it, as to heat it to redness. It is placed in the air chamber as shown in the figure and as the air chamber is made of brass, the battery connections are insulated at L L where they pass through the side of the instrument.

J is a glass cylinder forming part of the gauge, 2 inches high and ·8 inch in diameter closed at the top and bottom with brass caps cemented on. A small glass tube F extends from within ·05 inch of the bottom of the glass cylinder J, through its upper end to a vertical height of about 7 inches, where it is bent back to form the descending tube G, parallel to F till it terminates within the air chamber. Coloured glycerine is placed in the gauge-glass J, till it reaches to a height of half-an-inch. The remaining portion of the gauge-glass cylinder J contains air at a pressure which exercises sufficient force on the glycerine to drive it up the glass tube F till it stands about half way up the tube. The sectional area of the cylinder J compared to that of F, is as 30 : 1, so that on the air in J expanding $\frac{1}{30}$th of an inch, the displaced liquid will rise 1 inch in the tube F. The height of the air column in the cylinder J is $1\frac{1}{2}$ inches. When it expands 1 per cent. of its volume, the liquid enclosed in J will be displaced to an equal extent, or 1 per cent. of 1·5 inch = ·015 inch and it therefore rises in the tube $\cdot015 \times 30 = \cdot45$ inch, but allowing for the back pressure due to the weight of the liquid in the tube F, it really rises ·4 inch. It is thus seen that a reduction of the normal air pressure of 1 per cent. in the air chamber E will cause the confined air in J to expand 1 per cent. and in doing so drive the liquid ·4 inch higher in the tube F. The reduction in air pressure in the

* See Transactions, South Wales Institute of Mining Engineers, vol. xv., pp. 39—43.

chamber E is brought about by burning out the firedamp which forms part of the mixture being tested, resulting in a partial vacuum in the air chamber.

To make a test with the indicator, the bottom of the air chamber is unscrewed,

Scale. ⅓ Full Size.

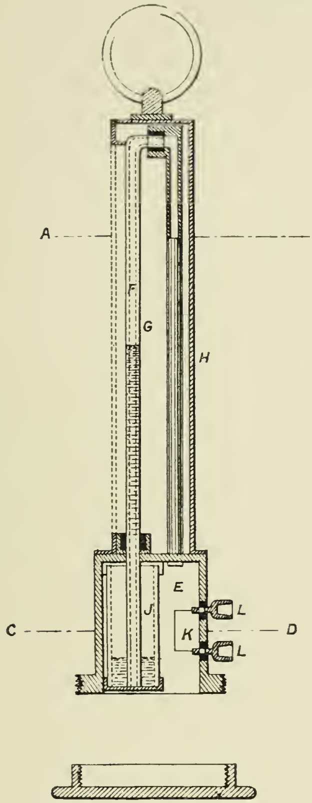


Fig. 396.

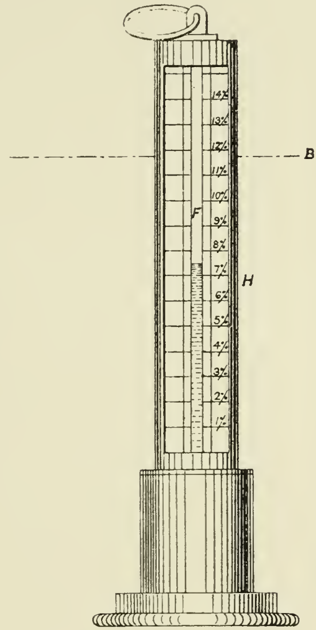


Fig. 397

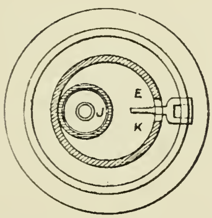


Fig. 398.—Section through C D.

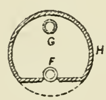


Fig. 399.—Section through A B.

LEWIS AND MAURICE'S FIREDAMP DETECTOR.

and the instrument held on its side, with the open end turned to the air-current so that the air enters and fills it. If out of a current or where there is not sufficient motion in the air, the instrument should be moved to and fro a few times. When the air chamber is thus filled, the cap is screwed on and the index finger or pointer attached to the scale is moved along it till it is level with

the top of the liquid in the gauge-glass. The indicator is attached to a battery which accompanies it, or a pocket accumulator designed for the purpose, and the current passed for 14 seconds. The per centage of gas present in the mixture (if any) will be shown by the liquid in the gauge-glass rising above the index finger, and this amount may be read off from the scale, which is graduated to $\frac{1}{4}$ per cent. but if smaller gradations are required they can be indicated.

The gas is not ignited, as in ordinary combustion, by the indicator, the temperature of ignition not being attained by the platinum wires, but as it in effect burns in the closed chamber a chemical change takes place. The platinum wire at a red heat burns the carburetted hydrogen. During the process, oxygen and hydrogen combine to form water which is dissipated in vapour, and carbonic acid gas is formed. As a result of the chemical changes, the products of the combustion plus the remainder of the air, occupy less space than that occupied by the original mixture of air and gas, and as the burning takes place in a closed vessel a partial vacuum is formed in it. It will be understood how the creation of this partial vacuum disturbs the pressure in the confined cylinder J.

It is necessary to accurately time the passing of the current, as the 14 seconds is the time required to burn half the gas in the air chamber and in graduating the scale the gauge is made to show the full quantity of gas when only half has been burned out, the rate of burning being uniform.

By placing the cylinder forming the lower portion of the glass-gauge J within the air chamber E, the air in both is subject to the same temperature at all times. If this were not so, the expansion due to heating the air in the air chamber by the platinum wires during a test, would depress the liquid in the gauge, but this is obviated by bringing the enclosed air in J under the same heating influence as that in E. Both may expand but they do so equally, so that the gauge is not affected when a test is made. Thus when the cap is unscrewed from the bottom of the instrument, the level of the liquid may be disturbed in the same way as that in a thermometer, but whatever level it assumes, after screwing on the cap with the test sample of air enclosed, the index finger is made to agree with it by sliding it along the scale.

CHAPTER XIV.

SUNDRY AND INCIDENTAL OPERATIONS AND APPLIANCES.

Carbonic Acid Gas Detector—Coal Dust—Watering the Underground Roadways—Explosives and Blasting Operations—Gunpowder—Gun-cotton—Tonite—Nitro-glycerine—Dynamite—Bellite—Useful Work performed by Explosives—Blown-out Shots—Johnson's Tamping Plug—Charging, Stemming, and Firing Shots—Experiments with Wooden Plugs for Tamping—The Water Cartridge and Accessories—Sand and other means of Protecting Cartridges—Tamping with Wet Moss—Roburite—Carbonite—Securite—Lime Cartridges—Wedges for Coal-getting—Macdermott's Rock and Coal Perforators—Ingersoll Hand-power Rock Drill—Ingersoll Machine-power Rock Drill—Gillott and Copley Rotary Coal-cutting Machine—Bower, Blackburn, and Mori Electrical Coal-cutting Machine—Stanley's Coal Heading Machine—Caging Appliances and Drop Staples—Pit Horses, their Food and Work—Fleuss Apparatus for Breathing in Noxious Gases—Fleuss Lamp—Exploring for Water—Underground Dams—Water-blasts—Underground Fires—Testing the Roof—Driving through Faults—Watt's Steam Indicator—Richards's Indicator—Use of Indicator Diagrams—Continuous Diagrams—The Thompson Indicator—Schäffer and Budenberg's Double Indicator—Bourdon's Pressure Gauge—Schäffer and Budenberg Bourdon Gauges—Steel Tube Gauges for Very High Pressures—Duplex Gauges—Graduating Ordinary Pressure Gauges—Graduating Steel Tube Pressure Gauges—Bourdon Vacuum Gauges—Schäffer Diaphragm Gauge—Testing Vacuum Gauges—Lightning descending Shafts—Dunford and Emen's Patent Automatic Tub-greaser—Self-lubricating Pedestals for Colliery Tubs.

CARBONIC ACID GAS DETECTOR.

An apparatus for ascertaining the amount of carbonic acid gas, or carbonic anhydride, in the atmosphere of a mine is shown in Fig. 400.* It is the invention of Herr Pieler, and consists of a burette B with glass cock A, the long stem C of the burette being graduated to indicate definite proportions of the contents of B. D is a three-way cock, and F a vessel for potass; E is an india-rubber pump by means of which the air to be experimented on is drawn into the burette through the cock A. When the burette is full the cock D is closed, and the contents of B are in free communication with the potass in F. The contents of F and B are then shaken together, causing them to mix as much as possible, when, if there is any carbonic acid gas in the burette B, it will have been absorbed by the potass, and its place will be occupied by some of the fluid passing out of F into C, and when F is moved up or down till the top of the fluid in F is on a level with that in C, so that no undue pressure may be exerted to raise the level in C, the gradations on the stem will

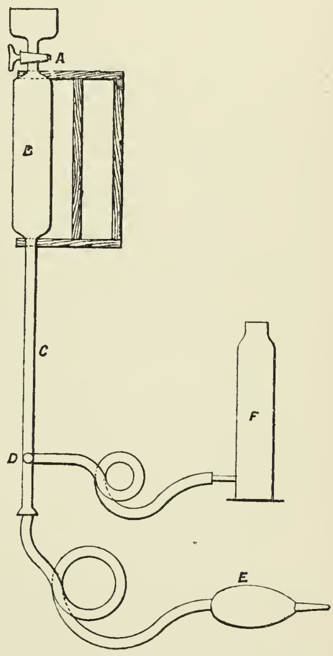


Fig. 400.—Pieler Carbonic Acid Gas Detector.

* See Transactions, North of England Institute of Mining Engineers, vol. xxxiv., p. 287.

indicate the percentage of the gas which previously existed in the mixture and was afterwards absorbed by the potass.

COAL DUST.

Closely connected with the lighting and ventilation of collieries is the effect of coal dust in promoting or increasing the disastrous effect of explosions. It is only of late years that attention has been to any extent directed to this question, but the experiments by Mr. W. Galloway (whose name will always be honourably associated with this matter), and those of the Royal Commission and others, prove beyond doubt that the existence of fine coal dust in the underground roadways and workings of fiery mines is a dangerous element, and that it has played an important part in colliery explosions. Coal dust consists of minute particles of carbon, and as these are mixed with the air in the workings they appear to be liable to combustion. The discussion on this subject is only now proceeding and definite conclusions on the subject have not been arrived at. It is doubtful whether explosions of coal dust occur on any large scale where the mine yields no fire-damp, although a blown-out shot may fire the coal dust. It is stated, however, that if a small quantity of fire-damp be present and fired in this way, its effects are much intensified and the explosion is extended along the roads containing coal dust, which thus feeds the flames of the explosion. Although there may only be a small quantity of gas, the flames, when thus started over a dusty road, are carried to a point far beyond that due to the simple explosion of the inflammable mixture of fire-damp and air. These facts are now fully recognised, and in dry fiery mines, where coal dust is largely produced, it is becoming a general practice to remove the dust, and to moisten the roof, floor, and sides of the roads. Mr. Galloway says that 1 per cent. of fire-damp mixed with coal-dust and air forms an explosive mixture. Sir Frederick Abel states that from 2 to $2\frac{1}{2}$ per cent. of fire-damp in the mixture is necessary.

From the remarks made on Ventilation, it is easy to see that any ventilating current after descending the downcast shaft will have its temperature raised as it passes round the workings; its capacity for absorbing moisture being thus increased, in comparatively dry mines the natural result of such absorption is to leave large quantities of dust. Nearly all deep mines are dry, and if fiery, as well, the usual practice now is to water them. A simple form of watering the roadways is by a water tram having a perforated pipe through which the water spurts out much in the manner of town water carts. This water tram may be attached to the sets of tubs on engine planes, or be hauled about by a horse. But the distribution of the water by this means is not very perfect, and latterly the watering of mines has been done by means of pipes and jets. In Mr. Blakemore's patent, a pipe is carried along the roadway to be watered at a convenient height above the floor. A parallel pipe, connected at intervals with the main pipe has continuous small perforations, the latter being in constant operation discharging jets or sprays of water. A cistern with an ordinary ball tap is placed at a suitable height in the shaft to get the required pressure, and this cistern supplies the pipes leading into the workings. The air current is thus kept moist as well as all the surfaces, and no dry dust can be raised.

In recent experiments made for laying the dust, efforts have been directed to the most suitable means for perfectly saturating the intake air, and from these it appears that this may be done by the use of specially made "spray-producers." From these the water issues in the form of spray or mist of such exceeding fineness as to be absorbed by the intake air to the point of saturation. This condition of the air is maintained by placing the spray-producers at suitable intervals along the roadway. A vertical branch pipe having an internal diameter of $\frac{1}{2}$ an inch is laid from the main road pipe to the roof and carried to the centre of the

roadway. The pressure of the water may be from 100 to 150 lbs. per square inch, and issues downwards through the spray-producers, which are placed at intervals of about 50 yards along the roadway. Each branch pipe is provided with a regulating cock.

At collieries where compressed air is used, a better result in the system of damping the intake air will be obtained by the use of compressed air in conjunction with water conveyed in the pipes as just described. A main pipe is necessary to convey the compressed air along the main intake, but probably that is already laid to supply some machinery in the workings. At each spray producer a $\frac{1}{2}$-inch branch pipe leads out of the main compressed air pipe and may be laid parallel to the water pipe branch. The compressed air-pipe is connected to the water-pipe by a nozzle in the interior of an ordinary T-pipe, which forms the junction of the air and water. The water is driven out by the air through an adjustable spray producer, which is regulated by means of a nut and screw. Spherical valves are placed in both the air and water pipes to prevent the water from passing into the air pipes and also the air from escaping into the water pipes should any accident occur to the water main. The air and water issuing at the spray-producer become mechanically mixed, in infinitesimal globules, and as the pressure of the air gives considerable impetus to these the moisture is carried further than with the globules of water unmixed with air. Consequently, where compressed air is used, the spray producers may be placed at greater intervals apart, probably from 100 to 400 yards, to suit the circumstances of each colliery. A further advantage of the air-and-water system arises from the fact that a much lower pressure of water can be used. Indeed, it is only necessary for the water to have sufficient pressure, when throttled down, to find its way into the chamber where the compressed air meets it and drives it out. In shallow pits, where no head of water can be obtained, this may be a better means of laying dust than adopting some expensive plan to get sufficient head of water.

The working faces may be damped as well as the main roads by either the water, or the air-and-water system. The pipes are laid to the face and the spray-producers fixed there. In compliance with the Act of Parliament, no shot is to be fired in the presence of dust, but if the dust is destroyed by damping, for a radius of 20 yards from any shot-hole and no fire-damp be present, the competent man appointed for the purpose may fire the shot.

EXPLOSIVES AND BLASTING OPERATIONS.

Probably no mining subject has had more attention during the past few years than that of blasting. By the Mines Act, 1887, various new restrictions are imposed on the use of explosives, both as to the actual process of blasting, and the places where it is permitted.

The use of explosives is intimately connected with the lighting of mines, and their freedom, or otherwise, from gas and dust. Thus, wherever safety-lamps are used shots can only be fired by or under the directions of a competent person appointed for the purpose. Similarly, wherever a mine is dry and dusty the same restriction is imposed. Further, where safety-lamps are used, the competent person may not fire a shot unless "he has examined the place itself, and all contiguous accessible places of the same seam within a radius of twenty yards, and has found such place safe for firing"; and if gas has been reported in the ventilating district at any of the four inspections recorded last before a shot is to be fired he must also examine the place or places, and see "that such gas has been cleared away, and that there is not at or near such place sufficient gas issuing or accumulated to render it unsafe to fire the shot," or if this is not the condition of the place as regards gas the shot can only be fired if it is "so used

with water or other contrivance as to prevent it from inflaming gas, or is of such a nature that it cannot inflame gas."

Then, if the place is dry and dusty (without reference to gas), such place and all contiguous accessible places within a radius of twenty yards, must be thoroughly watered, or have treatment equivalent to watering, but if watering would injure the roof or floor, then the explosive may be used with water or other contrivance so as to prevent it from inflaming gas or dust, otherwise the explosive must be " of such a nature that it cannot inflame gas or dust."

A further restriction is applicable to any part of a main haulage road, or place contiguous thereto, showing dust adhering to the roof and sides. Not only must the place of firing, and within a radius of twenty yards, be watered, or have treatment equivalent to watering, but the explosive must be used with water, or other contrivance, so as to prevent it from inflaming gas or dust, unless it is of such a nature that it cannot inflame gas or dust. An alternative to this is, that one of the conditions mentioned must be observed, and all workmen—except those engaged in firing the shot, and others (not exceeding ten) employed in attending furnaces, boilers, engines, signals, or horses, or inspecting the mine—removed from the seam or seams on the same level.

Thus it will be seen that, with one exception, greater stringency is now required in the matter of blasting than formerly. Under the Act of 1872, where gas had been found issuing so as to show a "blue cap" on the flame of a safety-lamp, shots could only be fired in coal-work when persons ordinarily employed were out of that part (which was decided to mean the "ventilating district") of the mine. Now, if certain safeguards are employed, shots may be fired with all the men in the mine.

Where an explosive is required in the actual getting of coal, as in those cases where the reduced percentage of large coal and its enhanced cost with hand labour alone do not result in a fair profit, *Gunpowder* is still found the most suitable agent.

As used in mining, gunpowder is a mechanical mixture of charcoal, sulphur, and saltpetre, in the proportion of 65, 15, and 20, respectively, out of 100 parts. Charcoal and sulphur, which inflame readily enough in air, are consumed more quickly if supplied more freely with oxygen. The saltpetre, closely incorporated with the sulphur and charcoal, supplies the necessary oxygen, and thus promotes rapid combustion. The explosive force of gunpowder depends on the sudden formation of gases, chiefly nitrogen and carbonic acid, which, at the high temperature at which they are evolved, amount to about 2,000 times the volume of the powder employed. The granular form of the gunpowder increases the rapidity of its combustion, as the flame is better able to penetrate it, and thus kindle every grain almost at the same time. For this reason, in mining, where it is desirable that the combustion should be comparatively slow, the powder is coarse-grained. The temperature at which it explodes is about 600° F. Although the principal products of its combustion are carbonic acid and nitrogen, with the vapour of water, carbonic oxide and sulphurous acid are sometimes produced in rather dangerous proportions. The combustion being comparatively slow, the pressure resulting from the expansion of the gases has more time to act on the mass, and, in coal-getting, to rend it without much shattering effect, thus admitting of larger coals being obtained than by the aid of a quicker explosive.

A great drawback to the use of gunpowder in mining is the large amount of flame emitted from the shot on ignition. This emission of flame is a thoroughly recognised element of danger in mines producing fire-damp, especially where they are dry and dusty; and even without fire-damp many mining engineers, managers and others, are firmly convinced that there is considerable danger in using powder where a place is dry and dusty. Without actually prohibiting its

use, the Legislature has endeavoured to minimise the risk in both cases by the stringent regulations already referred to.

Cartridges made of compressed gunpowder have been used during the last few years, the object being to obtain within a minimum volume a given store of power. These cartridges are very convenient, being purchased ready for use, and obviate the danger attending the making of cartridges from loose powder, which operation is often left for the miners to do at their homes. Where the shot-hole can be bored truly circular there is no practical objection to the use of compressed-powder cartridges. Numerous accidents have, however, happened with them, probably caused by the cartridges having exploded owing to the heat generated by excessive friction while being forced into holes either too small or not truly circular.

The Mines Act, 1887, prohibits explosives being taken into a mine except in cartridges, unless such mine is exempted from the clause by order of the Secretary of State. Although not expressed, probably it is the intention of the Act that the explosive shall not only be taken into the mine, but also be used in cartridges —unless the mine is exempted. The grounds for claiming the exemption are not stated in the Act, but apparently this provision is intended to meet those cases where it is more practicable to use powder in the loose state, and because of a difficulty in boring holes round enough for cartridges, which difficulty undoubtedly exists in certain kinds of rock, and even in fireclay containing nodules of ironstone.

Modern explosives are, for the most part, nitro-compounds in some form, and these may be reduced to two, viz., gun-cotton and nitro-glycerine.

In the manufacture of *Gun-Cotton*, cotton waste is steeped in a mixture of sulphuric acid and nitric acid. During this process three equivalents of hydrogen are removed by the oxidising action of the nitric acid, and replaced by three equivalents of nitric peroxide. After steeping, it is washed in water, and cleansed from acid, following which it may be stored, or converted into other compounds. Although its constitution is different from what it was when placed in the bath, its appearance remains the same.

Gun-cotton explodes at 400° F., and as gunpowder explodes at 600° F., gun-cotton may be fired on gunpowder without igniting it. It has double the explosive force of gunpowder, and has the advantage of yielding no smoke. Time, moisture, and exposure do not alter its qualities. It is exploded by detonation. Cotton-powder is gun-cotton reduced to a fine state of division.

Tonite is cotton-powder, with the admixture of a nitrate or similar body.

In the manufacture of *Nitro-Glycerine*, a similar chemical change takes place to that obtained in the manufacture of gun-cotton. In this case the nitrification of a liquid is effected, viz., glycerine. Glycerine is mixed with nitric acid, and the mixture allowed to fall or drop in a narrow stream into water, when the nitro-glycerine immediately separates.

The action of the nitric acid removes three equivalents of hydrogen, and replaces them by equivalents of nitric peroxide, and without apparent change in the material.

Nitro-glycerine in its liquid state is inconvenient to use. Moreover, it is highly dangerous while in this condition.

It is susceptible to ignition in two ways. If burned at the wick of an ordinary spirit lamp, and the experiment be conducted by a skilful operator, it burns quietly and harmlessly. This experiment is too dangerous to be entrusted to any but skilled hands. Similarly, gun-cotton may be comparatively safely lighted by applying a flame to it, when it will burn rapidly without explosion. When nitro-glycerine or gun-cotton are ignited by means of a detonator,

extreme rapidity of decomposition and combustion follow, and cause a violent explosion.

Dynamite is manufactured by impregnating a spongy kind of clay, called kieselguhr, with nitro-glycerine, in the proportion of 25 parts of the former to 75 parts of the latter, so as to form an explosive of a less objectionable nature. When in a proper condition, dynamite is plastic, safely handled, and very convenient for use as an explosive. Irregularly shaped shot-holes may be charged with it. It does not explode by spark or flame, but by detonation.

When the cartridges are below 32° F. in temperature, they will not explode except with difficulty; indeed, they are not in a safe condition when under 40° F., at which temperature the nitro-glycerine in them freezes. When in this condition they require to be thawed, or "tempered," before use, and this operation should only be attempted by the use of a "warming-pan," such as the makers of dynamite supply, and the instructions issued by the makers with each packet of cartridges should be strictly adhered to, in order to prevent accident.

The explosion of pure nitro-glycerine being so much more destructive than that of an equal weight of dynamite, efforts have been and are still being directed to substitute for kieselguhr (which is an inert substance) some absorbent body which will also assist the explosion. Thus, Litho-fracteur has a proportion of clay, with saltpetre and sulphur. Other combinations have been tried, all of which act very similarly.

Shots charged with the nitro-compounds, or high explosives, as they are sometimes called, are violent in their action, and shatter the material in which they are exploded. Although unsuitable for coal-getting, they are most usefully applied in extra strong rippings, in stone drifts, in sinking shafts, or where the presence of water interferes with the easy use of powder.

Bellite is a new explosive, and is said to be as explosive as No. 1 dynamite, although it is not a nitro-glycerine compound. It is the invention of Mr. Carl Lamm, and is composed of four to five parts by weight of ammonium nitrate, and one part of dinitro-benzene. The powder has a yellowish colour, is almost dry to the touch, and, as it is said to act like the best slow powders, is very useful for coal-mining.

The actual work performed by any explosive used in blasting operations is limited by incomplete combustion, compression, and other changes in the material operated on, energy given out in cracking and heating material not displaced, and escape of gases through the shot-hole and fissures caused by the explosion. The useful work produced by various explosives has been estimated at from 14 to 33 per cent.

BLOWN-OUT SHOTS.

When the explosion of a shot results only in the blowing out of the stemming, or in doing little or no work, it is said to be a "blown-out shot." This result may be caused either by the shot being badly stemmed, or by its being improperly planted with regard to the work which it is intended to do. In the blasting of coal, if the shot-hole extend even a short distance beyond the holing, so as to make a "fast-end," there is liability to a blown-out shot; in stone-work especially, unless skill is exercised in so planting the hole that it shall not have too much resistance, there is still greater liability for this to happen.

For years this subject has had considerable attention. It is a very important one, for undoubtedly many serious explosions have arisen through the flame from

a blown-out shot igniting gas, or gas and dust, and, in some instances, dust alone.

Experiments have shown that in air containing 6 per cent. of inflammable gas the flame from a blown-out gunpowder shot extends to 15 yards, but under such circumstances no shot should on any account be fired. Even with no gas the flame will reach a distance of 13 feet, with clay used for stemming.

Johnson's tamping plug is said to be a reliable remedy for blown-out shots. It saves time in stemming, and its use ensures getting the greatest possible amount of work from the explosive charge. It is said that it effectually prevents the shot from blowing out even in fast holes. A special drill has been designed to bore the hole, which is circular in shape. The plug is made of phosphor-bronze 14 inches long, and accurately fits the shot-hole. A small machine for making plastic pellets from the underclay of the coal-seam accompanies the plug and drill. After the explosive charge is placed in the shot-hole, to prevent the gases from entering between the plug and the sides of the hole, one or more of the plastic pellets is interposed between the charge and the plug. One or more of the pellets is placed over the plug outside and the tamping is completed. The pressure of the gases given off from the explosion must go on increasing till the material in which the hole is drilled, yields, or the whole of the charge is burned. Even with flameless explosives, the use of the plug is to be recommended, as it ensures the greatest possible effect from the charge used, and the plug may be used over and over again. To facilitate its recovery after use underground it may be painted white.

CHARGING, STEMMING, AND FIRING SHOTS.

The comparatively minor operations of charging, stemming, and firing shots are of sufficient importance to require careful study, for although they are left to ordinary workmen as a rule, they nevertheless demand skill and care on their part as well as direction and guidance on the part of those acting in the management. The firing of shots has always been a source of danger in mines, and with the view of the further diminution of accidents the subject has, under the Act of 1887, more restrictions imposed on it than formerly. Thus, it is now made clear that all iron or steel tools are prohibited in the charging and stemming of shots, the object being to guard against accidents from sparks kindling the charge prematurely. Coal or coal-dust must not be used in stemming, thus reducing the chance of a large flame issuing from the shot. There can be no doubt that the use of small coal for stemming lengthened the flame from a gunpowder charge very considerably. A further restriction is, that no explosive shall be forcibly pressed into a hole of insufficient size, which, again, is intended to minimise the risk of premature explosion.

The unramming of a shot which had missed fire was formerly an illegal act, and it remains so. Besides this, where a shot has missed fire, another hole for a charge shall not be bored at a distance less than six inches from the former.

There can be no question as to the necessity for these restrictions in the use of explosives, nor any doubt that the proper observance of the whole of the regulations relating thereto will tend to increased safety.

In the stemming of shots, probably no better material can be used than clay, made up in pellets. The mode of procedure is as follows:—After the charge has been carefully pushed to the end of the hole, a pellet of dry clay is first put in and pressed firmly against the charge, a copper or wooden rammer being used for the purpose. Other pellets are inserted, one at a time, and pressed in by the rammer, which may then be struck lightly by a hammer, and the operation repeated until the hole is filled. Where no suitable clay is available care should be taken to use a soft material, free from grit, but which is not of a coaly nature.

Shots are fired by the aid of either straws, paper squibs (each filled with fine powder), safety fuze or by an electric shot-firer.

Where a straw or squib is used, after the explosive charge has been placed in the hole, a copper pricker or needle is inserted, the pointed end being pushed gently into the charge, whether consisting of a cartridge or loose powder. The handle end of the needle projects from the hole a few inches. The rammer has a groove formed at its side, so that it may slide on the needle during the operation of stemming. When this is completed the needle is carefully withdrawn by giving it a twisting motion while doing so. The straw or squib is then inserted in the needle-hole, and the space between the stemming and the straw or squib closed at the mouth with a piece of soft clay. A "match," consisting of a piece of touch-paper, or a piece of lamp-cotton twisted straight and oiled, is fixed on the end of the straw or squib, and the shot is then ready for lighting.

An objection to both straws and paper squibs is that they may not always allow sufficient time for the shot-firer to be well out of the way before the explosion takes place.

In firing by means of safety-fuze a needle is unnecessary. The fuze is put in the shot-hole in contact with the explosive charge and the hole stemmed, the coating of the fuze preventing injury thereto during the process. The best fuze should be used. It burns at the rate of about 32 inches per minute, thus allowing more time for the shot-firer to withdraw to a place of safety. To ignite the fuze the shot-firer opens about an inch of the end into two or three parts, and fixes in it a piece of tinder or touch-paper. Where safety-lamps are in use, the touch is kindled by a fine wire passed through a hole in the gauze of a safety-lamp, the ends of the wire remaining in contact with the flame and the touch-paper respectively until the wire becomes red-hot and the touch burns.

Firing shots by means of electricity, although adding slightly to the cost, is doubtless the safest method that can be adopted. An electric fuze or "exploder" is required. It consists of some explosive compound which is capable of being acted on by an electric current so as to produce an explosion. One method of firing is by inserting in the exploder a fine platinum, iron, or alloyed metal wire, and connecting this with other wires in the circuit of a powerful voltaic battery. The fine wire not having sufficient conducting power offers sufficient resistance to the electric current to heat the wire to redness and thus cause an explosion of the compound in contact with it. Another method is to make a sudden discharge of static electricity take place between the terminals of two wires embedded in the charge. The passage of the sparks between the terminals causes the explosion of the fulminate, which then fires the shot.

An electrical machine for exciting and accumulating electricity, and conducting wires are also necessary. If it is desired, a large number of holes may be fired simultaneously. The usual practice is for the whole apparatus to be placed in the hands of a competent man, and an assistant, who travel from place to place, and charge and fire the shots if, after the prescribed examination of the place and its vicinity has been made, it is found safe to do so.

Some electric shot-firers test the caps before firing them.

In firing by electricity it is of the utmost importance that the wires or "cables" be left unconnected with the battery until everything else is in readiness and the persons present have removed from the position of the shot to a place of safety.

In charging a hole with cartridges of dynamite or similar compounds, one or more being used according to the charge required, each cartridge should be pushed quietly home with a wooden rammer. If safety-fuze is used, a suitable length is taken, and one end,—cleanly cut,—is inserted in a detonator-cap down to the fulminate, and the cap well closed over the fuze by pressing with circular nippers. In wet places, or if water is used in tamping, the junction of the cap and

fuze should be well greased. A small cartridge, called a "primer," is then opened for the reception of the detonator-cap, The cap, with the fuze attached, is inserted in the primer to a depth of about three-fourths of its length, and the paper covering securely tied round the fuze with string. The primer and fuze are then ready for being placed on the charge in the hole, after which some loose stemming is put in and the hole stemmed as may be necessary.

Where gunpowder is now used for blasting, it is usually in cartridges, and in damp places the cartridge-paper should be waterproof. If there be water entering the shot-hole through fissures, it should be kept back by clay well rammed into the hole.

Experiments have been made in ordinary blasting to ascertain how far wooden plugs pierced with a hole for the fuze, and 6 or 8 inches long, could be substituted for tamping, but they were not attended with much success. It was found that, in most cases, the gases escaped between the plug and the sides of the shot-hole before ignition was completed, and that the plug was blown out like a projectile.

THE PREVENTION OF FLAME FROM SHOTS.

Where blasting operations are unavoidable in mines which are either fiery or dry and dusty, it has become an absolute necessity to use means whereby flame shall not issue from the shot on its explosion, if the explosive used be one which produces flame.

Before the passing of the Act of 1887, however, efforts had been made to attain this object, amongst the first of which was the method of surrounding the charge by water before it was placed in the hole. This "water-cartridge," as it is called, is the invention of Mr. Miles Settle, and is used in conjunction with Nobel's gelatine-dynamite. When properly manipulated it is an effectual preventive of flame.

The *Water-Cartridge* consists of a cylindrical case of specially prepared water-tight paper, 18 inches long by 2 inches in diameter. In the centre of this case the explosive is placed and kept there by thin metal webs or diaphragms, the last cartridge or primer having inserted into it the detonator with wires for electric firing. The space between the charge and the paper cartridge is then filled with water, and the outer end firmly tied round the projecting wires. The charge is then ready for being placed in the shot-hole.

The *Gelatine-Dynamite* or *Gelignite* is a nitro-compound containing 80 per cent. of blasting gelatine (consisting of nitro-glycerine and nitrated cotton), 15 per cent. of nitrate of potash, and 5 per cent. of wood ground into fine powder and freed from all resinous matter.

The following information and instructions on the subject have been supplied by Nobel's Explosives Co., Limited, Glasgow:—

"The frequent recurrence of colliery disasters directly due to the use of blasting powder has drawn public attention, more especially in recent years, to the necessity for adopting some other method of coal-getting, and the efforts of many scientists and mining engineers have long been directed towards the attainment of so desirable an object. On the Continent, as well as in this country, Government inquiries have been instituted, and the study of this subject has led to a wonderful development in mechanical means of coal-getting, and in improved systems of blasting, accompanied by the introduction of new explosives, &c.; but, unfortunately, the majority of the inventions brought before the public have tended much more to increase the cost of obtaining coal than to advance the object in view. Among methods other than those which depended solely upon the use of mechanical appliances may be mentioned the hydrogen cartridge of Dr. Kosman,

the lime cartridge, the use of water-tamping and moss-tamping with explosives. Other systems, from their obvious impracticability, need not be referred to here, and of those mentioned above, none appear to have made any appreciable headway.

"To Sir Frederick A. Abel, C.B., F.R.S., the celebrated War Department Chemist, the principle of the water-cartridge, in its original form, undoubtedly owes its origin. So far back as 1880 this distinguished scientist conducted experiments in the Garswood Hall Collieries, near Wigan, which clearly demonstrated that dynamite, in conjunction with waterproof envelopes, might be effectively utilised in coal-blasting. These experiments were further pursued under the direction of the Royal Commission on Accidents in Mines, on which Sir F. A. Abel occupied a prominent position; and the results obtained showed that the adoption of a water-cartridge would eventually solve the difficult problem of safety-blasting in fiery mines and in the presence of coal dust.

"In the meantime, however, two events happened which were destined to have a most important bearing upon the question of safety-blasting. These were the patenting by Mr. Settle of his improved water-cartridge, and the introduction into Great Britain of the gelatine explosives of Mr. Nobel. Mr. Miles Settle, the managing director of the Madeley Coal and Iron Co., Madeley, Staffordshire, and of the Darcy Lever Collieries, Bolton, himself a practical coal worker of wide experience, conceived a method by which the safe use of the water-cartridge might be ensured, and his invention was patented in October, 1882. Meanwhile the gelatine compounds manufactured under the patents of Mr. Alfred Nobel were placed on the market; but it was not until after 1885, when these explosives had been brought into more general use by the introduction of two moderately-priced compounds, known as gelatine-dynamite and gelignite, that the advantages of combining their use with the water-cartridge became strikingly apparent. Among other facts which were brought into prominence by experiments conducted on behalf of the two patentees was the important discovery that the gelatine explosives invented by Mr. Alfred Nobel *possess in themselves* qualities which render these compounds specially suitable for safety-blasting. When used for blasting in the ordinary way they give off flame and sparks to only a very limited extent, and in this respect recommend themselves, even when employed without the water-cartridge, as yielding a degree of safety in coal-blasting to which no other explosive has yet attained. To this valuable recommendation they add the important distinction of being practically impervious to water, which is an advantage that is shared by no other explosive.

"The improved water-cartridge of Mr. Settle consists of a simple arrangement of discs or tin supports (see Figs. 401—404), whereby a most essential advantage is obtained, namely, the fixing of the explosive charge in the water-cartridge in such a manner that it is maintained in a central position so as to be *entirely surrounded by water*, at whatever angle the borehole may be placed. This invention of Mr. Settle obviates the danger which had hitherto existed of the explosive charge occupying a position of close proximity to the outer envelope, and in consequence exposing an unprotected side or end to a "blower" of gas, and thus facilitating the escape of flame and sparks, which cannot be prevented by a mere film of water, if even such were assumed to exist. In proof of the absolute necessity for fixing the explosive charge in a central position, it may be stated that, in numerous carefully-conducted experiments, *flame was observed when the explosive was left unsupported* and allowed to rest on the side or end of the envelope.

"Before acquiring from Mr. Settle his valuable patent, Nobel's Explosives Co., Limited, added still further proof of the reliability of the water-cartridge—if such were needed—by means of an elaborate series of experiments conducted by experienced mining experts in their employment, who submitted the patent

gelatine-water-cartridge to crucial tests far exceeding what would ever be required of it in actual use, and the results were in each case absolutely satisfactory. For instance, the experiment of firing the water-cartridge in a barrel containing a mixture of fine gunpowder has been frequently performed by the Company's experts without igniting the powder.

"It will be seen from what we have said that safety and the other advantages which we are justified in claiming for the patent gelatine-water-cartridge do not only rest upon the invention of Mr. Miles Settle, but upon the employment of the gelatine explosives of Mr. Alfred Nobel in conjunction therewith. The joint use of the two inventions is indeed a most fortunate combination.

"The adoption of the improved water-cartridge and the gelatine compounds by Mr. Settle in his Madeley and Darcy Lever collieries, which are undoubtedly among the most fiery in Great Britain, is a sufficient proof of the safety of this method of blasting. In the collieries referred to, many thousands of water-cartridge shots have been fired with absolute success during the past three years. In the Fair Lady Pit, at Leycett, Madeley, where, on 6th January, 1880, a disastrous explosion occurred, caused by a blown-out gunpowder shot, and resulting in the loss of sixty-two lives, no blasting of any kind was allowed until Mr. Settle introduced his water-cartridge. Since the adoption of this system, blasting has been regularly carried on for upwards of fifteen months with perfect safety, and to the entire satisfaction of H.M. Inspectors and of the workmen employed in the pit.

"It may be interesting to add that, between the 1st May, 1886, and the 31st August, 1887, nearly 300,000 shots have been successfully fired with the patent gelatine-water-cartridge.

"As proved by the experiments conducted under the direction of the Royal Commission on Accidents in Mines, all nitro-glycerine compounds do not possess in an equal degree the safety or advantages of gelatine-dynamite and of gelignite, which latter is another form of the same explosive. Dynamite, although it has been employed with the water-cartridge in several experiments with comparative safety, has in other instances shown sparks and flame, and, moreover, possesses the disadvantage, that unless each charge is protected by a waterproof covering it is liable to dangerous exudation of nitro-glycerine owing to the action of water.

"In view of the danger attending the use of dynamite, gun-cotton, tonite, gunpowder, and other explosives with the water-cartridge, Nobel's Explosives Company, Limited, consider they are justified in prohibiting the employment of the Settle water-cartridge in conjunction with any explosive compounds other than Nobel's gelatine-dynamite and gelignite."

The following description of the requisite appliances has also been issued by Nobel's Explosives Company:—

"ACCESSORIES.—*Water-Cartridge Cases* (Fig. 402).—These are manufactured from specially-prepared waterproof material. The water-cartridge case or bag in general use measures 18 inches long by 2 inches in diameter; but several other sizes may, under certain circumstances, be found to be more suitable, and these can be procured on application.

"*Gelatine-Dynamite or Gelignite Cartridges.*—These cartridges constitute the explosive charge, and are supplied of varying lengths, according to the strength of the shot required. Gelatine-dynamite and gelignite, when used in connection with the water-cartridge, may be considered to be about four hundred per cent. stronger than ordinary blasting powder. About 4 oz. of gelatine-dynamite, or about 4 oz. of gelignite, are therefore equal to 1 lb. of compressed blasting powder; but, as the results obtained in water-cartridge blasting are superior in many respects to those obtained by ordinary powder blasting, the regulation of

the charge can most readily be determined by experience. No other explosive than these two gelatinous compounds should be employed with the water-cartridge. One cartridge alone should be used, and on Fig. 401 B is shown the method of fixing the electric detonator fuse therein.

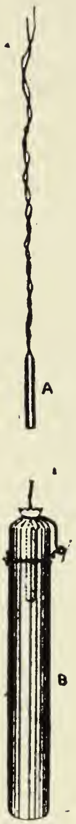


Fig. 401.

Fig. 402.

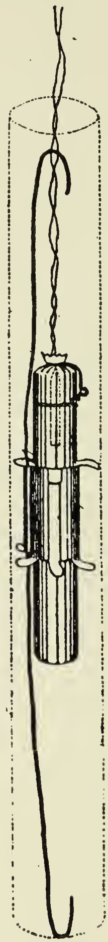


Fig. 403.

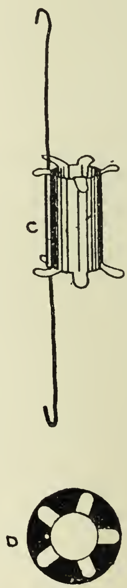


Fig. 404.

Settle's Patent Water-cartridge.

Fig. 401.—A, Nobel's Electric-Detonator Fuse. B, Cartridge of Gelatine-Dynamite, or Gelignite, with Electric-Detonator Fuse, showing Detonator inserted overhead and fixed ready for placing in Tin Support C.

Fig. 402.—Water-Cartridge-Case, prepared for insertion in Bore-hole.

Fig. 403.—Skeleton Water-Cartridge-Case, with charge in position.

Fig. 404.—C and D, Tin Support.

"In exceptional cases, where it is absolutely necessary to employ more than one cartridge, they should be connected by means of a wooden skewer (Fig. 405), and squeezed tightly together. Figs. 406, 407, 408, show cartridges so connected. This precaution prevents a film of water lodging between the cartridges, and thus tending to cause a miss-fire.

"The sizes of the cartridges usually employed in water-cartridge blasting are as follow, viz.:—

$\frac{7}{8}$ inch	diameter	×	$3\frac{1}{2}$ inches	long.
1 ,,	,,	×	5 ,,	,,
$1\frac{1}{8}$,,	,,	×	6 ,,	,,

"*Nobel's Electric Detonator Fuses* (Fig. 401 A).—These are thoroughly reliable,

Fig. 405.

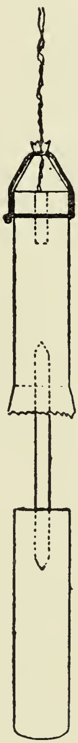


Fig. 406

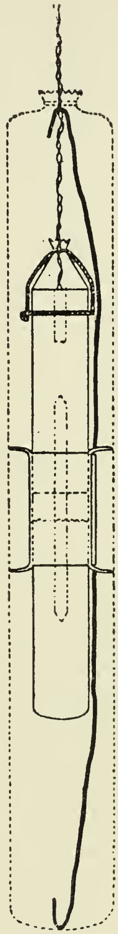


Fig. 407.

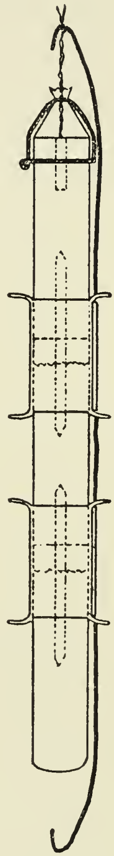


Fig. 408.

SETTLE'S PATENT WATER-CARTRIDGE.

Fig. 405.—WOODEN SKEWER FOR CONNECTING CARTRIDGES TOGETHER.
Figs. 406, 407, 408.—CARTRIDGES CONNECTED TOGETHER TO FORM ONE CHARGE.

and differ from the fuses of other manufacturers in several respects. They are usually prepared with wires 54 inches long, but, if desired, they can be furnished with wires of various lengths attached. Fig. 401 B shows the electric detonator fuse inserted into the cartridge, the detonator being pressed in overhead and the cartridge-paper tied over it, the twine being then twisted round the cartridge, to keep the whole in position.

"*Supports.*—These are made of tin, and are so formed as to suit any size of cartridge. Fig. 404 C, D show the tin support, and from Fig. 403 the method

Fig. 409.

Fig. 410.

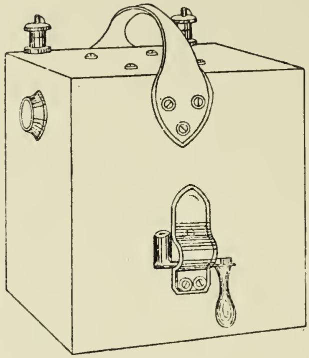


Fig. 411.

Fig. 412.

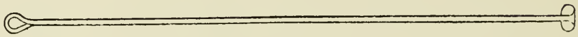


Fig. 413.

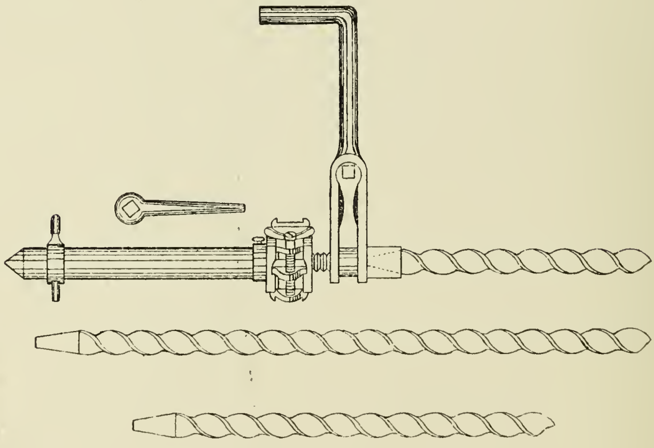


Fig. 414.

SETTLE'S PATENT WATER-CARTRIDGE APPLIANCES.

Fig. 409.—WOODEN TAMPING ROD.
Fig. 410.—FUSE PROTECTOR.
Fig. 411.—ELECTRIC BATTERY.
Fig. 412.—E and F, INSULATED CABLE.
Fig. 413.—SCRAPER.
Fig. 414.—MECHANICAL DRILL.

of fixing the supports on the cartridge of gelatine-dynamite or gelignite will be readily understood."

The following are the permanent appliances which (in addition to the "accessories") are required when Settle's water-cartridges are in use :—

Battery, or Magneto-Exploder (Fig. 411).

Insulated Cable (Fig. 412 E F).—Supplied with box and reel if desired.

Fuse Protector (Fig. 410).—A tapered hollow rod of Muntz metal for preserving the fuse wires from abrasion during the process of tamping.

Mechanical Drill (Fig. 414).—This machine is very strongly constructed, and is specially adapted for preparing bore-holes for the water-cartridge. It is most useful for coal, soft rock, or in moderately hard ground.

The feed of the mechanical drill is automatic, and so arranged that the screw may be instantly withdrawn to change drills. The standard is so constructed that it can be extended from its shortest length to within about one foot of double that length. All the parts of this machine which are required to withstand strain are made of steel, thus ensuring the greatest possible strength combined with lightness.

For *very hard rock* the Elliott drill should be used, and it will be found to bore any material capable of being penetrated by a rotary drill.

Tamping Rod (Fig. 409).—These are made of strong, tough wood, with ends pointed of Muntz metal.

Scraper (Fig. 413) is a rod of Muntz metal, having a flat disc of the same metal at one end, which is found of much use in clearing loose stone, &c., out of the bore-hole prior to inserting the water-cartridge.

The possibility of the water getting out of the cartridge before a shot could be fired suggested a means whereby this might be overcome, while the benefit of the water was still retained, and this was attained by adding a proportion of soap or other gelatinous substance. In this way, the cartridges are surrounded by a liquid which shortly "sets," and there is no danger of its getting out.

Another method is to use common sand moistened with water, the cartridges forming the charge being placed in the centre of the paper covering, which should be large enough to admit of a thickness of half an inch of sand all round. The paper cartridge for holding the wet sand should be made water-proof by soaking in oil or paraffin, and then dried.

Tamping the charge with wet moss is another means used for preventing the issue of flame, and appears to be fairly effective when used with gelatine-dynamite as the explosive.

FLAMELESS EXPLOSIVES.

Three of the new explosives are said to be flameless, and to provide in their composition all the advantages sought to be secured by water-cartridges, viz., roburite, carbonite and securite. The first, *Roburite*, has been tried and stood the test of exhaustive experiment in this country. It is the invention of Dr. Carl Roth, of Berlin. In appearance, it is like brown sugar, and if placed on a bright coal fire it burns away, but not vigorously. It is about three times as powerful as gunpowder, weight for weight, but about three times the cost. Roburite is a mixture of two compounds, which are kept separate until the employment of the explosive is required. Each of these compounds is harmless in itself, is inexplosive, and does not easily catch fire. The mixture of the compounds is done at central depôts, from which consumers are supplied. As showing how safe it is to handle after mixing, a light, if applied to it, does not produce explosion, but causes it to burn with moderate intensity. Neither friction nor percussion causes it to explode, and it is only when primed by a specially strong detonator that it *can* be exploded.

Cases are reported in which workmen have been injuriously affected by the fumes, or by handling the roburite. It is not, however, clearly proved that any injury to health has been caused by the fumes, and the precise composition of these, or the gases evolved consequent on the explosion of roburite, is a point which requires clearing up. With regard to the handling, this difficulty may be met by

not allowing the roburite to come into contact with any part of the person, to prevent which the cartridges may be made up into any suitable size before being sent to the pit. The Roburite Company issue full instructions, and, if these be strictly followed, injury to the workmen from handling will not arise. A smaller quantity of roburite is required for a given work than for some other explosives, a shot-hole $1\frac{1}{2}$ inches in diameter doing the same work as a $2\frac{1}{2}$-inches water cartridge, and thus effecting a saving in expense. With roburite the flame is quenched by the gases resulting from the explosion, the gases not supporting combustion.

In the beginning of the year 1889 two medical practitioners and the professor of chemistry in Owen's College were appointed to investigate the effects of roburite on the health of the workmen in the Park Lane Colliery, Lancashire. As a result of the investigation, the committee came to the conclusion that, with care, the roburite need neither be spilt nor come into contact with the hands of the operator, but in some mines proper precautions are not observed, and cases of undoubted nitro-benzine poisoning have been brought to the notice of the committee, due to improper manipulation of the cartridges. The committee also found that roburite, when properly confined, undergoes complete combustion, leaving no trace of nitro-benzine derivatives unburned, but that there is a chance of incomplete combustion occurring, owing to the explosive not meeting with sufficient resistance.

The following are the general conclusions and recommendations of the committee:—"That although roburite itself is a strong poison, and undoubted cases of poisoning have arisen from the use of it in coal-mines, yet, if stringent care is exercised on the part of the managers, shot-firers, and colliers, the use of roburite will not add to the harmful conditions under which the miner works. As indicating the directions in which additional precautions are in our opinion most necessary, we venture to add the following recommendations to our report:—(1) That the entire manipulation of the cartridges should be entrusted to special shot-firers, who should be instructed in their use. (2) That the effective tamping of the cartridges should be insisted on. Experiments would show by what means the complete combustion of the roburite could be invariably secured. (3) That every care should be taken to ensure the removal of the fumes from the working-faces before the return of the miners, *e.g.*, by continually bringing the brattice cloth up to the working-face. (4) That the products of explosion should be rapidly mixed with a large volume of air. We lay stress on the necessity for the carbonic oxide being diluted with a large quantity of air before it can be breathed with impunity by those who enter the mine."

Carbonite is said to resemble gunpowder in its action more than any of the new explosives, except that it is flameless when exploded. It is a nitro-glycerine compound, containing about 25 per cent. of nitro-glycerine absorbed in a mixture of wood meal, and saltpetre, with a little carbonate of sodium, and is made up into cartridges of $\frac{7}{8}$ inch or upwards. It is of a brownish colour, and being of a plastic nature it may be pressed into irregularly-shaped bore-holes so as to completely fill them. The cartridges may be stored for a considerable time without losing their efficacy. When struck with a hammer or stone it will not explode, and will only do so by a detonator. The power of the explosive, which is about twice that of gunpowder, is not reduced when placed in wet shot-holes. Many trials have been made with carbonite, and they prove that it is free from flame, even when exploded in coal-dust, under circumstances where the explosion of gunpowder and some nitro-compounds resulted in great flame and violent interior explosion.

Securite is a granulated powder of light yellow colour, with an odour of bitter almonds, and is the invention of Mr. Schoenewez, a German. It is made out

of the bye-products of coke-ovens and gas-works, is said to be efficient, and 35 per cent. cheaper than dynamite.

The products of combustion act as diluents of the oxygen in the air, but, it is stated, are otherwise possessed of no deleterious properties, so that no discomfort arises to miners using the explosive.

It is said to be about four times as forcible as blasting-powder. In wet holes it must be used in waterproof cartridges. It is claimed for it that it cannot be exploded by ordinary concussions or blows, nor by a burning or a glowing body. It is exploded by detonation. It is said to break down the coal in a similar manner to ordinary powder, and to destroy all flame and sparks within the range of the products of its combustion.

Recent reports of scientific men in Germany and France, who were appointed to examine into the question of explosives, state that these substances fired in a dangerous mixture of air and fire-damp ignite the mixture only when their temperature of explosion exceeds about 2,200 degrees Centigrade. The temperature of explosion of ordinary gunpowder is about 2,231° C., of nitro-glycerine about 3,170° C., of dynamite 2,940° C., and of cotton 2,636° C. Therefore it is possible for all these substances to produce an explosion of fire-damp. But if other substances can be added to these explosives so as to reduce their temperature of explosion to 2,000° C., or less, their use will be attended with perfect safety. Experiments appear to prove that an equal weight of either the carbonate or the sulphate of soda to dynamite renders the latter incapable of exploding a fiery atmosphere. Similar results follow from mixing a considerable quantity of finely powdered coal-dust with the dynamite. By experimenting further it is probable that suitable substances may be found, which, when added to any compound, will render its use safe.

The use of *Lime Cartridges* as a substitute for blasting has been tried within the last few years. The system is patented by Messrs. Sebastian Smith & Moore. Nearly pure carbonate of lime is used in the preparation of these cartridges. Being ground to a fine powder, it is by means of a specially arranged hydraulic-press subjected to a pressure of 40 tons simultaneously at both ends, by which means its density is nearly doubled. In their preparation a groove is formed on the side of the cartridges about half-an-inch in diameter. In the shot-hole an iron tube, half-an-inch in diameter and having a small groove on the upper side and provided with perforations, is inserted along the whole length of the bore-hole. This tube is enclosed in a bag of calico, which covers the perforations and one end, and has a tap fitted on the other. The cartridges are then inserted and lightly rammed so as to ensure their filling the bore-hole. Tamping is then used as with gunpowder, and a small force-pump being connected with the tap at the end of the tube by means of a short flexible pipe, water, equal in bulk to the quantity of lime used, is forced in. The water is driven to the far end of the shot-hole through the tube, escaping as it passes along at the groove and through the perforations and the calico, flowing towards the tamping into the lime, there saturating the whole of the charge and driving out the air before it. The tap is then closed, so as to prevent the escape of the steam generated by the action of the water on the lime, and the flexible pipe removed. The action of the steam first takes place, cracking the coal away from the roof, and this is followed by the expansive force of the lime.

In a seam of coal, having a good, smooth parting, this means of bringing down the coal after it is holed operates fairly well. If the coal be very strong it is not so successful, neither is it so where the coal is very open or porous, for the steam escapes through the pores and a great part of the force is thus lost. Probably for these reasons its use has not become at all general.

WEDGES FOR COAL GETTING.

Considerable attention has at different times been directed to mechanical wedges of various designs for breaking down coal, and thus to a large extent obviating the necessity for explosives in coal-mines.

There is no doubt that the best form of these mechanical wedges has the

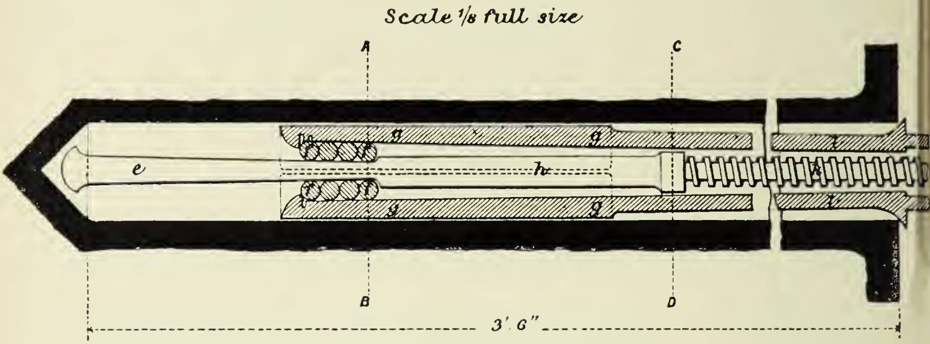


Fig. 415.

SECTION THROUGH A.B

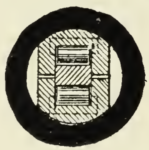


Fig. 416.

SECTION THROUGH C.D

Fig. 417.

Burnett's Patent Roller Mining Wedge.

advantage of an increased percentage of large coal in the output (and therefore a gain in the average selling price), as the use of the best explosives tends to shatter the cohesion of the coal.

A great obstacle to their more general use lies in the fact that they are not so easily handled by the workmen as gunpowder, and the yield of coal from them per day is less to the collier.

A form of this machine, known as Burnett's Patent Roller Mining Wedge, is shown at Figs. 415–417.

The action of breaking down the coal is by drawing the wedge *e* between the rollers *f*, working against two feathers, *g g*, which have been previously inserted in a bore-hole in the coal. The hole is about four inches in diameter. The wedge *e* is a prolongation of the bar *h*, which terminates in a screw, *k*, of such a length as to project a short distance clear of the bore-hole. The rods, *l l*, form a continuation of the feathers, *g g*, to the outside of the bore-hole. The necessary force to draw the wedge *e* forwards, is obtained by the backward and forward movement of a lever in communication with a ratchet-wheel, to which is attached a nut acting on the screw *k*, not shown in the drawings.

The wedge requires a bore-hole to be drilled $4\frac{1}{4}$ inches in diameter, for a depth of 3 feet 6 inches. The wedge-bar, *e*, projects 8 inches beyond the full diameter of the machine, and only a depth of 2 feet 10 inches of coal is forced

down at one operation. The other 8 inches is utilised when preparing the next bore-hole. It is very seldom necessary to draw the wedge quite home, and the process should take place slowly and intermittently to give the coal time to work.

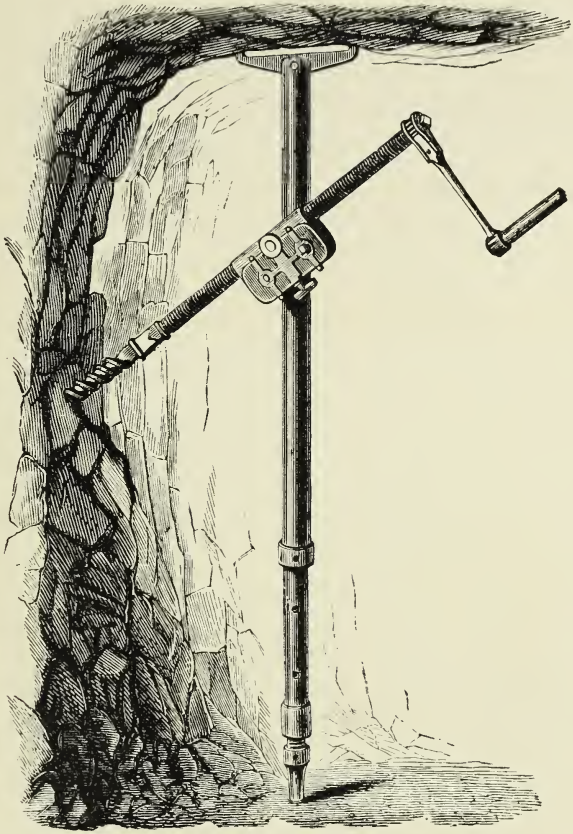


Fig. 418.—MACDERMOTT'S PATENT ROCK AND COAL PERFORATOR.

Hydraulic wedges are used much in the same way as mechanical wedges, their rending action resulting from the water pressure brought to bear on the wedge.

ROCK PERFORATORS AND HAND-POWER ROCK DRILLS.

For the most part, drilling the bore-holes for shot-firing or wedging is done by manual labour at the coal-faces in carrying on mining operations. In some cases, the operation is more easily performed by means of a coal perforator than with the usual drill and hammer.

A drawing of Macdermott's Patent Rock and Coal Perforator is shown at Fig. 418. It can be worked by one man, and will drill a hole at the top, bottom, or any intermediate point of the working, and at any required angle. It is very portable, and easily fixed in its working position. By means of the telescopic standard it may be fixed in roadways of varying height.

The standard may be fixed between the floor and the roof, or between any two bearing surfaces. At the upper extremity of the standard is a claw working on a rocking joint, the lower end has a nut fixed inside, on which a screw works. The screw terminates in a point, so that one or two turns of the screw suffice to render it absolutely fixed and rigid by driving the point into the floor and the claws at the other end to a solid bearing, whatever may be the inequality of the surface on which they rest. This constitutes the fixed portion of the implement. The working portion consists of a metal clip collar, hidden from view in the drawing, which slides along the whole length of the standard. The collar also revolves around the standard and can be clamped at any required point. To this is attached by a very strong conical joint the malleable iron box shown on the drawing, enclosing the mechanism for giving an automatic feed to the screw. By this means the screw and its attached tool are adapted to the varying hardness of the material to be pierced. Through the box the main or driving screw passes and is furnished at one end with a socket to receive the steel auger for boring the hole and at the other with a ratchet handle for turning the screw.

After the standard is fixed in position, the sliding collar is unclamped, and moved up and down to the required position where it is clamped; then, by making the box revolve on the conical joint the auger is adjusted to the angle and point required. A backward and forward movement of the ratchet handle causes the auger to revolve and penetrate the material in contact with it.

Several types of Macdermott's Perforators are made by Messrs. Glover & Hobson, Engineers, Albert Iron Works, St. James's Road, Old Kent Road, London, S.E. No. 1A being specially adapted for boring holes of great depth, such as those made in the neighbourhood of old workings, in advance of the face to test the presence of water. No. 2A is designed to bore holes immediately close to the roof of the mine, or contiguous to the floor. It is arranged so that a man may work the handle at the proper height for his arm whilst the machine bores a hole within one or two inches of the roof or floor.

Messrs. Glover & Hobson thus describe Macdermott's perforators :—

"The Patent Rock and Coal Perforators which M. Macdermott was the first to introduce belong to the class of machine-tools which have done so much of late years to increase and cheapen production in every Art and Industry. They perform, with great economy of labour, one of the most necessary operations in Mining. They will drill a hole, whether at the top, bottom, or any intermediate point of the working, and at any required angle, and are therefore invaluable for ripping down roof or forcing up floor (whether by powder or wedge), boring in advance for water, sinking shafts and making plug-holes in same, driving stone or metal drifts, &c., &c. The uniformity of the hole made by these implements renders it well adapted for cartridges, and gives the maximum effect of the explosive. No blown-out shots need be apprehended. The saving in the quantity of powder where these Perforators are used amounts to about 33 per cent. They are easily carried about, easily adjusted, and easily worked.

"The Patent Rock and Coal Perforators possess advantages which are peculiar to themselves. Firstly, the automatic feed by means of which the same machine can be adapted without alteration to varying hardness of material. Secondly, the adjustment which enables the drill to *be withdrawn instantaneously*, and without any danger of clogging in the hole. Further, they will drill in any required direction equally well; the hole made is uniform throughout its length; any unskilled labourer can use them; one man can carry about, fix, remove after fixing, and work them; and last, though not least of their advantages, they will enable one man to do the work of four—and frequently the work of six—drilling with jumper or hammer and chisel in the ordinary way."

Messrs. Legros, Mayne, Leaver & Co., of 60, Queen Victoria Street, London,

E.C., supply the Patent Ingersoll Hand-power Rock Drill, which is specially designed to be worked by hand in places where steam or compressed air is not available, and shown at Fig. 419. It is simple in construction and as nearly as possible resembles the Ingersoll machine-power drill, having a cylinder in which is placed a volute spring (as used for railway buffers) of 200 lbs. power; this is compressed by a bar which is lifted by cams on the crank-wheel shaft, and its release gives the blow; rotation and automatic feed being at the same time provided for. The 200-lb. spring, weight of drill rod, and the momentum produce a very efficient blow, while the form of the spring and other parts render renewals rarely necessary. All working parts are made of steel and the wearing parts hardened. Three sizes of drill are made, one being for a single man-power, another being a 2 man-power and a third suitable for working with 4 men. With a 2-man power machine about 250 blows per minute may be struck, drilling in granite from $1\frac{1}{2}$ to 2 inches per minute.

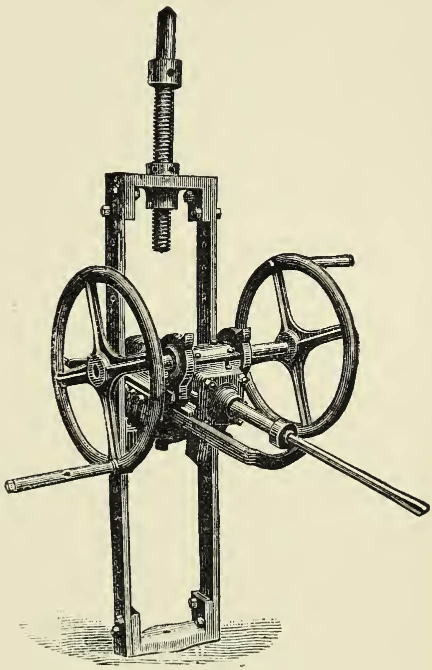


Fig. 419.—Ingersoll Hand-power Rock Drill.

The subjoined directions are given for the use of the drill:—

"First fix the drill on the tripod (or column) by the centre-bolt on the frame of drill, then set the legs of the tripod with the drill vertical or angled, as may be required. Insert a short drill-bit into the end of working rod, and secure it by tightening the screw of the clip. Loosen the nut on the top of feed-screw, and wind the drill down until the drill bit presses on the stone, then tighten the nut on top of feed-screw and commence working, going on until the bit is deep enough, or as far down as possible, then loosen the nut on top of feed-screw and wind back the drill to the highest point, when the drill bit can be taken out of its socket and a longer one inserted for drilling deeper holes, this being repeated until the necessary depth is bored.

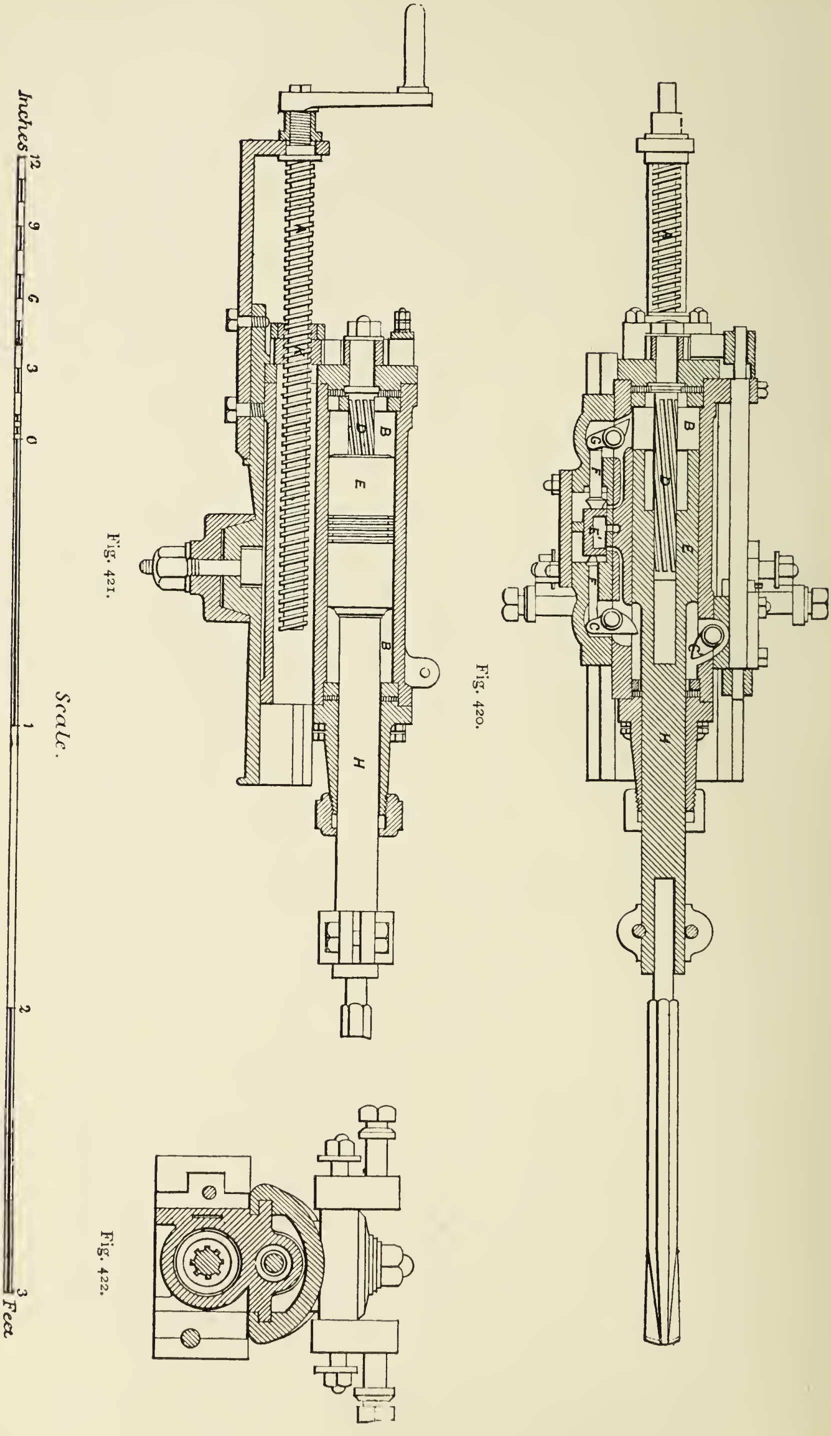
"The automatic-feed is worked by the conical part on top of the working rod, and this cone should be under the top edge of cylinder cover when the drill is down on the rock. Note.—The nut on the top of the feed-screw must be screwed down tight before the drill will feed automatically.

"The shaft and cams may be removed by taking the four screws out of the cap in front of shaft.

"The working rod and actuating spring may be removed by taking the nuts off the bottom cover of cylinder.

"The wearing parts of crossbar may be renewed by turning the crossbar round back to front, and again by turning crossbar upside down (to do this take off the spring and unscrew collar nut, turning crossbar top to bottom to replace), and again by turning crossbar back to front, thus utilising four different wearing surfaces.

"The working rod and the cams should be kept well lubricated."



Figs. 420–422.—The Ingersoll Machine-power Rock Drill as formerly made.

MACHINE ROCK DRILLS.

The necessity for driving headings, or for sinking shafts rapidly, calls into requisition machine rock drills as a substitute for hand labour in boring holes for shot-firing. In various forms these operate on the rock with a percussive action, as in the ordinary hand drill.

One of the best is the Ingersoll Machine-power Rock Drill, shown in the drawings, Figs. 420–422. It consists of a cylinder B, in which works the piston E, H being the piston rod. The valve-gear is actuated by the piston through the medium of tappets. It consists of a slide valve E′, two valve spindles F, F, and the two tappet levers C, C.

The piston, as it moves backwards and forwards, alternately encounters and depresses the limbs of the tappets which project into the cylinder, as shown on the drawings; and as these limbs move simultaneously, the motion thus communicated is transmitted by the valve spindles to the slide valve. The tappets are so adjusted relatively to the stroke of the piston as to admit of a cushion (of steam or air) being formed at either end of the cylinder; this cushion prevents injury to the cylinder covers and preserves the drill from excessive vibration.

A spirally grooved bar D, recessed into the back end of the piston, gives a rotary motion to the drill. The piston has a cap screwed into it fitted with studs to run in the grooves of the bar.

A ratchet-wheel is fixed to the end of the bar, and into its teeth a pawl is held by a spring. By means of the pawl, the piston is compelled to turn during the back stroke, whilst allowing the spiral bar to rotate during the forward stroke. Besides the automatic rotary motion of the drill now described the feed motion in the Ingersoll rock drill is produced automatically, so that as the borehole advances the cylinder equally moves forward and there is no diminution in the force with which the drill strikes the rock. As the drill penetrates the rock, the piston approaches the forward end of the cylinder, and strikes against a tappet lever C′ which partly rotates the rod on which it is carried. By means of pawls and ratchet teeth, this rod turns a nut upon the back end of the cylinder. The feed screw A passes through this nut, which in the act of rotating upon the fixed feed screw causes the cylinder to advance.

The drills used are of different sizes, according to the work to be done. A $2\frac{1}{2}$-inch cylinder drill is capable of boring a hole from 1 inch to $1\frac{3}{4}$ inches in diameter 8 feet deep. The motive power may be either steam or compressed air, the usual working pressure being 45 lbs. per square inch.

For shaft-sinking the drill may be carried on a tripod, or on a special shaft-sinking frame. For driving headings it may be supported on a stretcher-bar. This is a wrought-iron hollow tube, provided at one end with a claw, and at the other a strong adjusting screw lock and nut for fixing it in position. For more important tunnel work the apparatus is mounted on a tunnel-car, specially designed for the purpose. This carries four drills.

The rate of progress by rock-boring machinery is from 3 to 12 times greater than by hand-labour, according to the hardness of the rock.

The only objection we have heard against the above described form of the Ingersoll rock drill is that when heavily driven, the tappets are apt to break, followed almost certainly by injury to the cylinder through the broken pieces jambing the piston against the walls of the cylinder.

Since the foregoing description and remarks were written, a new type of Ingersoll machine power drill has been devised. In it the use of tappets is dispensed with and also the stems which acted in conjunction with them to move the valve across its face. The valve is now formed by a segment of a circle, and is brought in direct contact with the piston, where it acts in the place of a pair of tappets by

receiving a gentle push from the inclines on the piston, instead of the blow formerly given by the piston to the tappets, and thus admits the motive-fluid fore and aft alternately into the cylinder, while at the same time the fluid keeps it firmly up against the face.

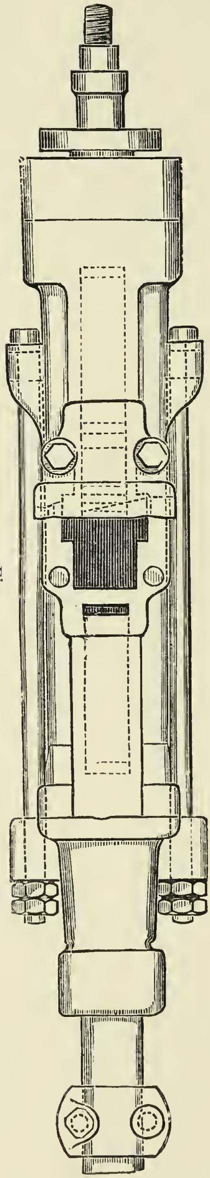


Fig. 424.

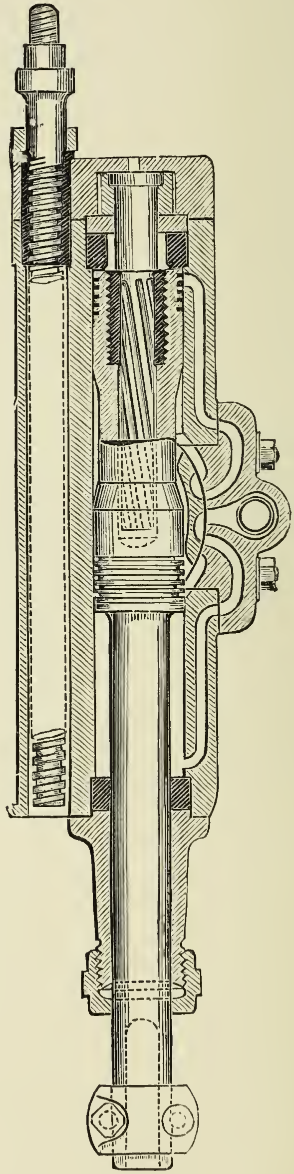


Fig. 423.

The Ingersoll Machine-power Rock Drill as at present made (1890).

The following particulars are supplied by Messrs. Legros, Mayne, Leaver & Co.:—

"Fig. 423 shows a section, and Fig. 424 a plan of this new patent drill, which has been designed specially with a view to reduction of cost, and simplicity,

durability, and economy in working, combined with increased efficiency in operation.

"This new patent is of the direct-acting percussion class of drill, and has the following distinguishing features and advantages:—

"1. Its Valve Motion.—This is entirely unique, and while retaining a positive motion of the valve (a most important feature), all moving parts between the piston and the valve, such as tappets, valve-stems, levers, &c., are entirely done away with, the valve itself being the only moving part remaining, as will be understood from the illustration and the following description.

"The piston has two fitting portions, divided by a recessed, or smaller portion, having gentle inclined planes at either end; this space round the centre portion of the piston forms the chamber into which the steam or air is first admitted. The valve is over this central portion, and is in form a segment of a circle, about (in the 3-inch drill) 4 inches long and 2 inches wide, fitting accurately against a curved face in the valve-chest. The upper side of the valve is provided with recesses properly proportioned, to admit the motive power past the valve to the ends of the piston.

"The steam or air being admitted into the central portion of the cylinder presses the valve closely to its curved face, and the piston being at one end of the stroke as shown, one end of the valve has been raised by the inclined plane, and moved around a portion of the curved face, sufficient to open the passages for the admission of the motive-fluid to the other end of the piston, forcing it along the cylinder, when, as it arrives at the proper position, the valve is again moved round its curve by the other inclined plane, and the steam (or air) admitted to the other end, reversing the motion of the piston and completing the stroke. By this it will be seen that the only moving pieces are the piston and the valve, and the actual results of this simple arrangement are *less wear, less liability to derangement, and the striking of a harder blow with less consumption of motive-power*, the valve being kept firmly up to its seat at any angle or at any speed.

"2. Its Rotation.—The rotation is effected, as in the original Ingersoll, by means of a rifled bar, and ratchet wheel having double pawls, this being the most reliable and positive motion obtainable; but in the new patent drill, the mechanism, instead of being exposed, is entirely enclosed, thus avoiding all chance of damage through dirt, grit, or rough usage.

"3. The New Patent Drill, like the original Ingersoll, can be used, and is equally efficient, in any position, either vertically for drilling upwards or downwards, horizontally, or at any angle, this peculiar arrangement and form of valve keeping in its place, and working well under any conditions.

"4. Provision is specially made in all sizes for taking up the wear in the saddle or slide.

"5. Durability.—In the construction of this drill none but the very best materials are used, and the workmanship is of the highest class, thus insuring the maximum of durability in a machine subjected to the hard work and rough usage of a rock drill.

"The improved drill, as shown at Figs. 423 and 424, is adapted for hand-feeding, and is suitable for an operator who, if not attending to the feed, would have nothing to do but look on. The same machines, however, are supplied with the automatic feed in an improved form, especially where the drills are used in groups, the number of operators being thereby decreased. The present arrangement for obtaining the automatic-feed is simpler and more efficient than the old one. In it the spindle is still retained, having a tappet keyed to the bottom with a sloping side, which projects into the cylinder in such a way that when the piston slides past it a turn is given to the spindle, which thus disengages a pawl at its top-end from the feed ratchet, and a coiled spring in a box then acts on the pawl, and pushes it into the ratchet again, sending it down the feed-screw. The action is

the reverse of the old style, in which the tappet causes the pawl to be thrust sharply into the ratchet, and the spring disengages it, whereas, in the present form, the effect is ensured by a more gentle motion, and with fewer parts, the knuckle-joints, separate tappet, and feed-regulator being dispensed with. It is now intended to extend the side bolts so as to take the back as well as the front cylinder-cover, and in the automatic-feed drills these have to be set slightly on one to allow the spindle to occupy its proper position.

"In the hand-drill shown in Fig. 419 the automatic-feed is obtained by the cone at top of the working rod acting on the feed ratchet by means of a lever, spring, and pawl, the cone in effect taking the place of the tappet in the power-drill."

COAL-CUTTING MACHINERY.

The labour of coal-getting is arduous even under the most favourable circumstances, and in thin seams it is especially severe and trying, owing to the constrained and unnatural attitude of the collier during the time he is at work, and more particularly at the work of "holing."

It is considered allowable, with good and skilful hewing, to take a height not exceeding 9 inches for the holing when carried to a depth of 3 feet.

Where the holing is altogether in the coal, and the seam thin and hard, hand-hewing is placed at a great disadvantage, because the coal obtained as a result of the holing is much less than that obtained from the same depth of holing on thick seams, the labour of holing in which is much less. Coal-cutting machines have been designed, and are in use to some extent, for undercutting the coal. Where circumstances admit of their use they save the collier the heaviest part of his toil. There is, however, great difficulty in the general adoption of coal-cutting machinery, on account of the undulating character of the seams, and the resulting irregularities of roof and thill over very limited areas. These irregularities form great obstacles to the smooth working of coal-cutting machinery, besides which, some districts are so much intersected by faults breaking the continuity of the coal-seams that machinery for getting the coal is quite out of the question. Other coalfields are more favourably situated, and on economical grounds it may be judicious to adopt coal-cutting machines.

The following description of the Gillott & Copley Rotary Coal-Cutting Machine is furnished by Messrs. John Gillott & Son, of Barnsley:—

"The machine described below has now been over 13 years in practical operation, under a variety of circumstances. It is designed for holing or undercutting, and is more especially adapted for collieries worked on the "Longwall," or some similar system, where a considerable length of face can be operated upon.

"It is driven by compressed air, and works at the low pressure of from 20 to 30 lbs. per square inch. This is of great importance, as when this pressure is exceeded it is attended with considerable difficulty, and a largely increased cost.

"It can be made to cut level with the floor, in a parting between two coals three feet or more above the trams, or at any other height; and is applicable for any seam of coal where a height of not less than 20 inches can be afforded for it to travel along the coal face.

"It will cut in fire clay seating, *hard or soft coal*, or take out a pricking between two coals.

"It is self-propelling, is made to suit the gauge of any colliery tramway, and travels on the rails as ordinarily laid by the colliers. No fixing is required to keep the machine up to its work.

"The machine is made principally of steel, thus combining the greatest strength with the least weight in the smallest space. It is made in three sizes; in the largest machines the frame, which is of crucible steel, is about 5 feet 6 inches long by 2 feet 4 inches wide, and on this are fixed two cylinders 9 inches in diameter,

with a 9-inch stroke, working on to a forged steel crank-shaft, which by a simple arrangement drives the pinion which gears into the slots of the cutter wheel. This wheel, which is of best crucible steel, is carried by a steel bracket, projecting horizontally from the side of the machine. It makes about six revolutions per

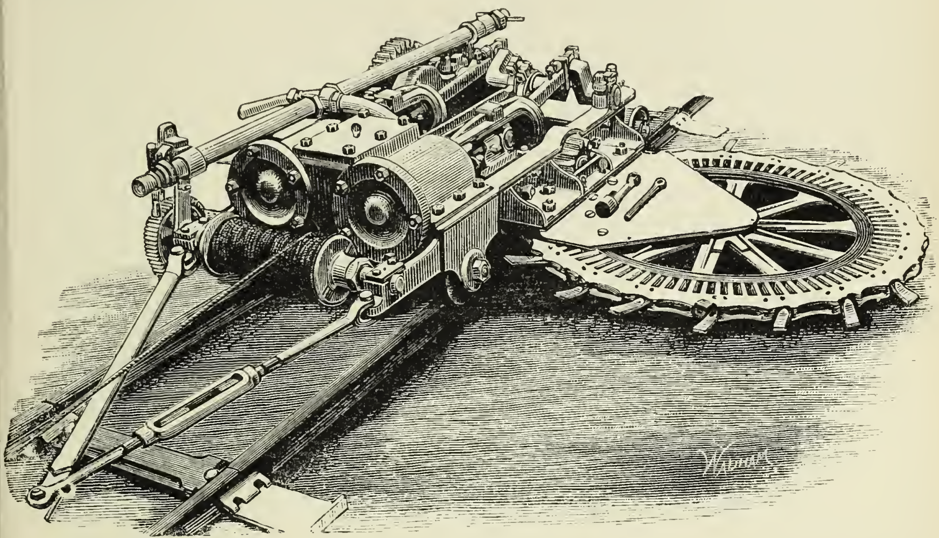


Fig. 425.

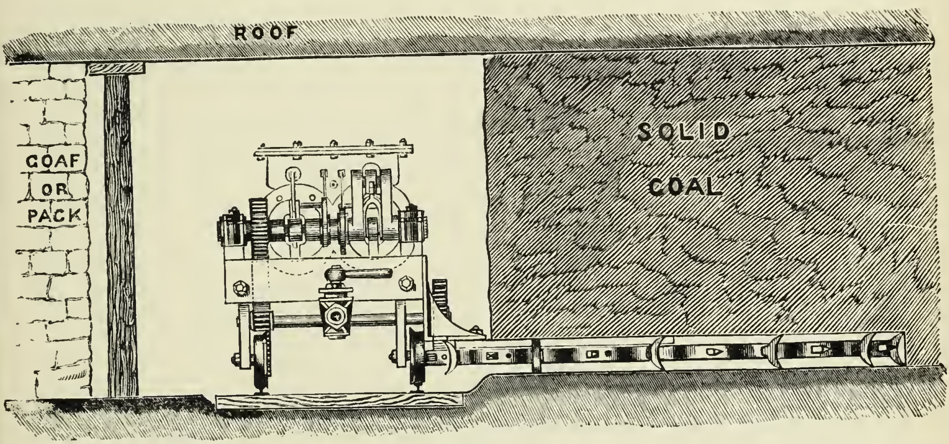


Fig. 426.

The Gillott and Copley Rotary Coal-cutting Machine.

minute, and on its outer edge or periphery are fixed from twenty to thirty steel cutters, thus giving from 120 to 180 strokes per minute; it is 4 feet 1 inch in diameter, and makes a clean cut of 3 feet 6 inches deep by 3 inches wide, from which it effectually sweeps out the whole of the cuttings as it revolves. The cutter-wheel is easily removed by slackening four bolts, and then the machine can be run to any part of the workings where it may be required. The cutters, which

are made of the best tool steel, require less keeping in repair than the ordinary picks, and are about 4 inches long. In the smaller machines the cylinders are $7\frac{1}{2}$ inches in diameter, with a 9-inch stroke, and cutter wheel 3 feet 10 inches in diameter, cutting 3 feet 4 inches deep.

"The machine is propelled by a small wire rope fixed to a bridle, passing round a snatch-block at the far end of the 'face,' and on to a drum at the front end of the machine, which is actuated by a ratchet wheel and lever worked by an adjustable crank, so that the feed or pace of the machine can be regulated according to the nature of the material it has to cut. The whole is covered with a moveable sheet iron casing to protect it from anything falling from the roof. One man only is required to be in attendance on the machine, and another should follow to sprag the coal as it is cut.

"*Working power.*—With a pressure of 27 lbs. per square inch of compressed air, the machine has holed in a hard tough fire clay seating $25\frac{1}{2}$ yards in 40 minutes, and 24 yards 1 foot of strong solid coal in 55 minutes with only 20 lbs. pressure. A fair average rate of work with 27 lbs. pressure may be stated at 20 yards per hour, 3 feet 4 inches under and 3 inches thick, either in a seating or moderately hard coal. The rate of holing by manual labour in the fireclay seating above named is about 7 yards for a day's work—this gives about nine men working a whole day to do what the machine does better in two hours. The men have only to wedge or shoot the coal down and clear it away while the machine is taken to another bank to do its work there.

"Several important improvements have recently been made which enable the machine when used to cut in either direction, and thus work backwards and forwards across the face, obviating the necessity of removing from one end to the other.

"*Compressed Air* is now often used for underground hauling and pumping, and when this is the case, the coal cutter may be applied at a trifling cost. In other cases estimates may be obtained for the complete air-compressing plant."

Messrs. Bower, Blackburn and Mori have patented an Electrical Coal-Cutting Machine. It consists of a frame travelling on wheels carrying the electric motor, driving a shaft which carries the cutter attached by bolts to a coupling. The motor and the shaft carrying the cutter-bar, can together be rotated in a horizontal plane, so as to bring the cutter in and out of the coal. The motor drives the cutter about 600 revolutions per minute, and develops from 6 to 9 actual horse-power according to the difficulty of cutting the seam.

The machine makes a cutting 3 feet 6 inches deep in the coal, only removing 4 inches in the operation.

A winch is used for drawing the machine along the face, and the under or over cutting is thus carried along the face of the uniform depth stated.

The electric current is produced by a dynamo placed on the surface, and transmitted to the motor in the workings by means of two small cables. Lead-sheathed cables are used in passing through wet places or those subject to foul air. They may be carried on insulators along the roadway or fixed on a wood casing to the roof or floor. At the face it is more convenient to use a double insulated cable, both wires being in one covering. By means of screw connectors this can be attached at any point to the main cable. The position of the main cable can be readily altered.

Including all stoppages, to put up props, &c., 45 yards per hour have been cut with the machine, and in actual cutting time 30 yards have been holed in 36 minutes in hard dirt with pyrites and ironstone lumps. It is claimed for this machine that the form of cutter (which is of special construction) obviates difficulties met with in some other machines, viz., the jambing of the cutter by the falling coal and consequent stoppage.

In a fiery mine the emission of sparks at the electric-motor or elsewhere may be a fatal objection to its use there, unless an efficient covering or protection be devised.

STANLEY'S COAL-HEADING MACHINE.

In carrying on the many operations incidental to coal-mining, circumstances may arise which necessitate long headings or narrow places in the coal being rapidly driven. The use of a machine, such as that designed by Messrs. Stanley Brothers, enables a much greater rate of progress to be attained than is possible by hand-labour. The machine runs on wheels in the heading. Attached to the inner end of a central shaft are a radial and two horizontal arms. Cutters are fixed on the horizontal arms, which, as the central shaft is rotated, cut an annular groove in the coal and form a core within it, which is removed from time to time as the work proceeds. There are two sets of gearing for working the machine. That in front causes the shaft and arms to revolve. This is effected by admitting compressed air to the two cylinders carried on the framework which give motion to a shaft connected with the central shaft by means of cog-wheels, through which the motion is transmitted. The back set of gearing provides for the forward motion of the cutters in operation. The central shaft is threaded so that the back gearing, which consists of a cog-wheel with threaded gun-metal bush fitted into its boss, works on it. The back cog-wheel is secured to the frame, and may be driven by a sliding cog-wheel working on the crank-shaft. On setting the back gear into motion, the frame advances on the central shaft; when the machine has been moved forward, the back gearing is thrown out, the front gearing thrown in, and the central shaft and arms advance in the frame, at the same time that they are revolving. The machine is provided with two telescopic screw-pins by means of which the frame is held securely in position while the cutters are at work. The usual size of machine weighs two tons, and the cutters form a heading five feet in diameter, at the rate of about three feet in an hour. The arms can only advance between three and four feet; and when out their full length the engines are stopped; the back gear thrown in, and the frame advanced and secured in position again for a further cutting. Different types of the machine are made to suit the varying qualities and classes of coal seams and their thickness.

CAGING APPLIANCES AND DROP STAPLES.

A serious loss of time occurs at collieries in changing tubs where the shafts are deep, if cages having two or more decks are used, and the ropes are lapped on drums in the ordinary way, unless some caging appliance be used. The inconvenience and loss are enhanced if there are intermediate loading stages in the shaft between the surface and the bottom.

In order to avoid having more than one loading stage in the shaft, drop staples are often used for lowering the coal from an upper to a lower seam, or the same object is attained by means of a self-acting inclined-plane driven across the measures between seams of coal.

Drop staples are fitted with guides or conductors precisely the same as the winding shaft. Two single-decked cages are used in the staple by means of which the full tubs are lowered, while the empty tubs are raised. The weight of the full tub or tubs is sufficient to effect the change. A single rope is generally used, which is attached to the upper cage in the usual way, passed over a clip-pulley, and the lower end attached to the cage at the bottom. The clip-pulley is held securely in its place by framework a few feet above the seam. Rails or flat-sheets are laid at the loading and unloading stages to facilitate the entry or

discharge of tubs at the cages. The clip-pulley is provided with a brake-ring, by means of a brake acting on which, through levers, the velocity of the cages is controlled and regulated by the upper-stage attendant, and an up and down signal are provided. Both at top and bottom shaft gates are placed for the protection of workmen and others moving about, those at bottom usually being hinged, while those above are lifted by the ascending cage and dropped into place again, when it is lowered in the same way as shaft gates. Where the distance between any loading stage and the bottom of the shaft is great, the expense and loss of power involved will be too great to allow of the expedient of a drop staple, and it is necessary to use the shaft loading stage. In such a case, if the quantity of coal coming from the workings to the shaft bottom is about equal to the quantity coming from the loading stage above, and is likely to remain so, it is usual to make the drums of the winding engine of unequal diameters, so that one cage is raised and lowered on one side of the shaft while the other is lowered and raised on the other side. Thus, one cage is used to raise the coal from the loading stage in the shaft and the other from the bottom. Where the quantity of coal reaching the shaft at one stage is greater than at the other, and in all cases where there are two or more intermediate loading stages in the shaft, great inconvenience in the caging must follow. Loading stages in the shafts, therefore, should be avoided as far as possible.

In the case of a shaft in which coals are only wound from the bottom in a single-decked cage with one or more tubs in it, no inconvenience arises in the change of tubs, which takes place in the most expeditious manner possible, being effected at the top and bottom simultaneously without moving the engine.

With a double-decked cage the tubs in the decks cannot be changed at the same moment in the ordinary arrangement. If the ropes are arranged so that the top deck of the cage at the bottom is exactly level with the flat-sheets or rails there when the bottom deck of the other cage is on a level with the rails at bank, after the change is effected in those decks, on moving the winding engine there will be an unequal travel of the cages owing to the greater length of rope unwound for the surface cage compared with what is wound on to the drum of the other cage. This inequality will be greater or less in accordance with the depth of the shaft, the thickness of rope used, and the kind of drum. When the top deck is lowered into position for changing at the surface the lower deck of the other cage is not raised sufficiently to allow of the change taking place at the pit bottom, and consequently it has to remain stationary, in a position out of the onsetter's reach, while the surface change takes place, after the completion of which it is raised and another stoppage occurs at the engine in order to change the lower deck of the cage at the bottom.

With a treble-decked cage the inconvenience in the change of tubs is increased, as all decks except one must be changed on the surface and underground at different times. Each stoppage of the engine means an additional shock to the ropes, which are thus subjected to greater strains, and so wear out quicker.

Fowler's patent apparatus for loading and unloading pit cages has been designed to overcome these difficulties. In it with a three-decked cage, the lowest tier rests on a level with the bank rails, and two three-decked platforms, one on either side of the cages, are arranged so that the change of the three tubs or rows of tubs takes place at the same time. One of the platforms contains three rows of empty tubs, which are on a level with the decks of the cage when the change takes place. If a single tub is placed in each deck the lowest tub is changed by hand in the usual manner. At the same moment, however, two hydraulic rams push the two upper empty tubs against the full ones in the cage, which are displaced and give way to the empties. The full ones pass into the platform provided for them. The empty tubs are kept in position in the cage by means of catches operated by a single rod.

After the cage has left the surface, the two platforms are lowered by means of hoists, deck by deck in succession, on to the bank level of rails; the full tubs are taken to the screens, and empties placed in the platform arranged for them. Counterbalance-weights raise the full platform after it has been relieved of the full tubs, and the other is also raised with the empties in it ready for the next change.

A similar arrangement is placed at the shaft bottom by which the tubs there are changed at the same time as those at the surface, so that the cages make trips in the shaft as expeditiously as single-decked cages.

Where there are only two decks to the cage, a much simpler appliance is frequently used to facilitate the change of tubs. It consists in placing a platform on the surface above the bank level which receives the full tub or tubs from the upper deck of the cage. After the descent of the cage, the platform is lowered to bank level by a counter-balanced cage which lifts the empty tub or tubs into position.

At the pit bottom the change is effected by means of a balanced platform. It is made large enough for both cages, and is suspended in the sump by means of two ropes, each of which is attached to a drum provided with counterbalance-weights and a brake. After the lower deck has been changed, the onsetter lowers the cage (there being sufficient slack rope for the purpose) till another deck is level with the pit bottom rails, using the brake to do so. After the ascent of the cage the counterbalance-weights raise the platform to the landing, and so places it in position for the next cage. Two or three decked cages may be unloaded and re-charged in this way very advantageously.

PIT HORSES, THEIR FOOD AND WORK.

Questions relating to the care of pit horses, although not directly engineering matters, are yet of great importance to the manager in the economical working of a colliery. Even with an efficient system of mechanical haulage, horses are still required in the remote workings. The aim should be to reduce their number as far as possible and to take the utmost care of those which are necessary. In South Wales, even where all the haulage on main roads is done by mechanical means, there are as many as 100 horses employed at a single colliery.

Horses are usually sent into the pit when four years old; ponies when three; their length of service there depends upon a variety of things, but the average may be taken at about eight years. If heavily worked and badly treated they may not last as many months.

It is hardly necessary to say that much judgment and knowledge are requisite in purchasing horses. The shape and appearance of a horse at rest and in motion afford some indication of his character, to those trained in the study; while the incisor teeth bear marks by means of which the age is ascertained, but unless a manager is versed in the anatomy and the important points of a horse, he had better not trust to his own judgment, but be guided by a qualified veterinary surgeon. In any case, it will be wise for him to buy from a trustworthy dealer, who regularly supplies the district, and will guarantee age, health, soundness of wind and limb, and freedom from vice.

The water given to the horse should be soft and pure, and of moderate temperature, and care must be exercised in timing the supply. When in a heated condition, the horse should not be allowed to drink too freely, nor should he remain too long without water. The diet must be regulated to suit the labour and the conditions under which it is performed. A high temperature, such as that often existing in underground roadways, tends to maintain the heat of its body, and a horse working therein will not require so much nourishment as when doing the same amount of work in a lower temperature. The stomach of the

horse is smaller in proportion to its body than that of any other herbivorous animal, and it therefore requires a little food frequently rather than a larger supply at longer intervals. Where at all heavily worked it should be well fed.

The food consists of grain and hay, the daily allowance varying with the work done. As an average it may be taken at about 16 lbs. of grain and 10 lbs. of hay per horse. The grain is for the most part Indian corn, but beans, oats, and peas are given in smaller proportions. The oats should be sound, sweet, a year old, and their natural weight not less than 40 lbs. per bushel. Musty or kiln-dried oats are injurious to horses, and cause colic amongst them, the chief symptoms of which are a tight, dry skin, loss of appetite and debility. The husk of the grain is nearly indigestible, and there is a greater per centage of husk in oats than in the other grain given to horses. The beans and peas should be sound and sweet; they have a heating and binding effect upon the system, and are therefore used in small quantities, or combined with some other article of food which has a counteracting effect, such as bran and maize. Colic in horses is caused by constipation or is accompanied by it; maize has a slightly laxative action on the bowels, and its use reduces the risk of colic to a minimum.

Hay varies in value according to the grasses it contains. If stacked wet or too green, it will ferment. Horses prefer the best seed hay to the best old land hay, and eat more of it, but the latter is more nutritious, and the smaller quantity eaten keeps them in good condition. They do not thrive so well on foreign as on English seed hay, as the seeds are usually thrashed out of the former.

At some collieries it is usual to give green food to the horses for a few weeks in the summer, and it is found to be very beneficial as an alterative and preserver of health. It must be given cautiously, especially for the first time in the season, and should not be allowed at all on the horse-roads or pass-byes. It consists of clover, seeds, and green tares well podded, sent into the pit only on dry days. It is more economical than dry food.

Of late years it has become the practice to use "ensilage," which is fodder stored in a green state. After being cut in the field in the usual way, instead of being dried it is chopped up small and put into pits or "silos," which are bricked and lined with cement. The green food placed in the pit is pressed down by stone flags on the top so as to exclude the air and consequently prevent fermentation. The upper layers are depreciated, but those below remain much the same as when cut.

Experiments show that dry food is more economical besides being more convenient to handle than ensilage.

As horses age, their grinder-teeth become worn, so that they are unable to properly crush such substances as Indian corn and beans; the grain therefore is partly crushed or bruised, the hay chaffed, and the whole of the ingredients thoroughly well mixed together before the horse is fed with them. The object of chaffing the hay is to prevent waste. When sent down the pit in bundles, a certain amount is damaged or lost in transit, and some is pulled from the racks and trampled under foot. When chaffed it is mixed with the other ingredients forming the provender, placed in bags and sent into the pit, where it is used without waste. Occasionally bran forms a part of the horse-food, and as it acts as a laxative may be most beneficially given at times. In food consumption three 14-hand ponies are usually considered equal to two horses, and one horse costs about ten shillings a week to keep, more or less according to the price of hay, &c.

Some disadvantages of underground horse labour may be mentioned. The number of working days at a colliery seldom exceeds 300 per annum, and is usually rather less. The cost of horses for food and attendance on idle days, such as Sundays, holidays, and those resulting from depression in trade, strikes, accidents, and diseases, adds materially to the cost of production. Horses are subject to epidemics, and it may happen that in times of the greatest prosperity some or

all of the horses may be unable to leave the stables. Delays are occasioned by full tubs leaving the rails, when the drivers have to traverse long distances for assistance in order to lift them on again. Other delays arise from horses dropping shoes while at work, when the shoeing-smith must be sent for; if the workings are far from the shaft, a considerable time is taken up before the shoer reaches the horse, during which, and also while the operation of shoeing proceeds, both horse and driver are standing idle. Horses receive injury from falling in the workings, or running away and wedging themselves into roads too low for them, and many are injured or killed by falls of roof, run-away trams, explosions, &c. Besides which there are the injuries inflicted by thoughtless, stupid, or brutal drivers—boys or men.

As to the work performed by horses, much depends upon circumstances. On a favourable road having a slight descent for the full tubs a 14-hand pony may be able to draw 10 tons at a time. But if the inclination is very favourable to the out-going trains, it must necessarily be unfavourable to the in-going. The best result is obtained from horse-labour when the resistance to the trains is equal both ways. If the road is muddy, or the tubs inefficiently greased, or the rails badly laid or worn, a large portion of the energy exerted by a horse is lost in overcoming extra friction, so caused. Again, where a horse works up a steep road, a considerable jerk and strain are necessary to start the load, especially if the back wheels near the face are beyond the rails and rest on a miry or uneven floor. Such strains are very injurious to the animals. Other things diminish the value of a horse's energy, such as a roadway with loose metal, or irregular floor, or one insufficiently ventilated.

The tractive force of a horse working on the surface is usually taken at 125 lbs. when moving at the rate of three miles an hour. If the force exerted by a horse is taken at 33,000 lbs. raised one foot high per minute, maintained throughout a day of eight hours, it amounts to 150 lbs. conveyed a distance of twenty miles, at a speed of two-and-a-half miles an hour. Mr. Nicholas Wood calculated the tractive force of a horse at 120 lbs. when travelling at the rate of from two to three miles an hour, and estimated that it could continue this for ten hours. Allowing for stoppages a speed of from two to three miles an hour = 200 ft. per minute. $120 \times 200 = 24{,}000$ foot-lbs., or say ten tons as the work per minute. Ten tons for twenty miles = 200 tons one mile per day. Mr. Wood takes two-thirds of this as the useful performance, thus $200 \times \frac{2}{3} = 133$ tons conveyed 1 mile a day. This is taken as the maximum effect that a horse can produce, when working on the surface. From experiments made at different collieries it appears that only about one-fourth of this useful effect is obtained from horses working underground. These may be taken to exert a tractive force of about 40 lbs. when moving at the rate of three miles an hour, which may be continued over a period of ten hours inclusive of all stoppages, say twenty miles a day, when the resistance is equal in both directions. If it is necessary to exert a greater force than 40 lbs., the distance travelled must be correspondingly less. If the force be 100 lbs., then $\frac{100}{40} = 2\frac{1}{2}$ times increase; therefore the distance travelled will be $\frac{3}{2\frac{1}{2}} = 1{\cdot}2$ mile an hour. Or we may say the useful performance of a horse underground is to convey about 45 tons one mile per day. Some horses travel from twenty to twenty-five miles in a shift underground, others do not exceed six. The heavier the gradient and the more irregular the roadway, the less will be the distance travelled.

No rules or calculations of this sort can apply generally; they must be taken as mere approximations, for the results obtained will vary in different collieries and districts. It may be useful to compare the actual performances of horses from

time to time, and to keep a record for future guidance. Suppose a horse works in a road leading from a shaft the rise of which is 1 in 130. The empty tubs weigh 5 cwt. each and would hold 15 cwt. of coal; the train consists of four tubs, and the friction is $\frac{1}{70}$th. The total weight of the full train is four tons. The assistance obtained from the outward fall is $\frac{4 \times 2{,}240}{130} =$ say 69 lbs. The resistance due to friction is $\frac{4 \times 2{,}240}{70} = 128$ lbs., so that $128 - 69 = 59$ lbs. as the effective resistance to be overcome in moving the full train. The total weight of the empty train is one ton. The resistance resulting from the inclination is $\frac{1 \times 2{,}240}{130} =$ say 17 lbs.; that from friction $\frac{1 \times 2{,}240}{70} = 32$ lbs. and the total, therefore, is $32 + 17 = 49$ lbs. The mean resistance of the two trains is $\frac{59 + 49}{2} = 54$ lbs. If the length of the horse-road is say 400 yards, and thirty-three journeys are made by the horse in a ten-hour day, then the inward and outward journey will be 800 yards, and $\frac{800 \times 33}{1{,}760} = 15$ miles a day travelled; this gives an average speed for the horse of $\frac{15}{10} = 1{\cdot}5$ mile an hour inclusive of stoppages. $\frac{1{\cdot}5 \times 1{,}760 \times 3}{60} = 132$ feet per minute, and $54 \times 132 = 7{,}128$ foot-lbs., or $3{\cdot}182$ tons for fifteen miles $= 3{\cdot}182 \times 15$, or $47{\cdot}73$ tons conveyed one mile a day.

The kind and the size of horse purchased for colliery working will of course depend upon the specific work for which it is required, the nature of the roadways, size of tubs, &c., &c., and in order to prevent the risk of importing infectious diseases into the underground stud, and to ensure new horses being well up to their work, they should be employed on the surface for three or four weeks before being sent into the pit.

Horses are lowered down the shaft by the cages if these are large enough; but if not the animals are securely fastened by a net and suspended below the cage.

At some collieries in South Wales no horses are stabled underground. Where the number employed in a colliery is small, and the cages large, it is found advantageous to lower and raise the pit horses daily, the time occupied in so doing being but trifling. After the day's work is finished each haulier takes his horse up the shaft and away to the stables on the surface. Before commencing work each haulier takes his horse to the pit and down the shaft again.

Generally, however, horses are stabled underground, and many that are taken down never see the daylight again. Usually, the most advantageous place for the stables is near the upcast shaft, and they may be made all together or in a series, according to the number of horses and the state of the strata. The proper ventilation of the stalls is of great importance, the current of foul air passing direct to the upcast. Where the workings are at a considerable distance from the shaft, stables are often made in the interior of the mine so as to avoid unnecessary travelling. An objection to this arrangement, however, is that splits of fresh air must be taken off the main current for their ventilation, thus reducing the quantity for the workings generally. The floors of the stables should be laid with blocks or planks of wood; a branch channel formed in each stall; the floor sloped slightly towards the channel from each side, and the main and branch channels given a definite inclination, so that all liquids will run to a given point. Sawdust is often spread over the floor for the horses to lie on, straw being an expensive litter. In South Wales ferns grow in abundance on the hills close to the collieries; these

are cut and when dried make a very good litter much used in the district. It is well by such means to encourage horses to lie down, for it has been ascertained that on brick floors only 10 per cent. of the horses lie on them, 20 per cent. on cemented floors, while the proportion rises to 70 per cent. on cemented floors if thickly covered with sawdust, and 70 per cent. on a wooden floor. Horses which never lie down are, in a few years, seized with numbness of the limbs, and consequently fall down when at their work.

Mangers should be not less than 2 feet by $1\frac{1}{2}$ feet, and 15 inches deep. A strip of wood two or three inches wide may be placed at the top projecting inwards so as to prevent the fodder from being thrown out. A strip of hoop-iron may be fixed to the top of the manger so as to prevent injury from the horses' teeth. Iron mangers are sometimes adopted, and iron props for the roof and for stall divisions; and occasionally brick mangers resting on stone bases 18 inches high and lined inside with cement. These are more generally built in stables near the shaft, while the iron ones are more applicable to those in-bye.

In the matter of cost, while avoiding extravagance on the one hand and meagreness or faulty design on the other, comfortable stables may be made at about £2 per stall. The site selected should have a good fall for drainage and have an opening not less than 17 feet wide. This will allow for a 6-foot roadway in which to lay a tramway along the whole length of the stables, leaving 11 feet from the gates to the head of the stalls. Stalls should be 6 feet wide, separated by props which secure the roof and form a sufficient partition without being boarded up.

Great attention must be paid to the shoeing of horses, the shoe being shaped to fit the horse's foot, and not *vice versâ*. Improperly shod horses worked on hard ground soon suffer from bad feet. The harness must fit easily and comfortably on the horse or he will receive injury from its chafing. Tight or rough collars rub the skin till a wound is formed. By the Mines Act, 1887, every travelling road on which a horse is used shall be of sufficient dimensions for the animal to pass without rubbing against the roof or timbering. All projecting stones and angular corners must be removed from the sides, so as to prevent injury to the animals.

The number of horses under one ostler or keeper should not exceed ten, and of ponies fifteen. Each keeper grooms and feeds his horses, and cleans out the stables. Besides receiving the attention of keepers, a pit's horses are generally under the periodical supervision of a farrier. There should be sufficient horses at a colliery to supply the daily requirements without having to work them double shifts, for systematic overworking is not only inhuman but also (happily) very costly.

In some districts it is customary to work the horses in traces: in others limbers are used, which give considerable holding-back power not to be had from traces. There can be no objection to traces on a level or nearly level roadway, and the harness is of course lighter without limbers. Where trace-horses take full tubs down hill, sprags are often placed in the wheels so as to act as a drag. Over very steep portions of roadway a sprag in each wheel may not be sufficient to prevent a speed which would be dangerous to the horse in front, and where this is so, besides the sprags, additional means are used so as to reduce the speed. In Somersetshire, *e.g.*, this is secured by passing a chain round a road-post at the top of the steep; the roadway being straight allows of the chain working between the rails. The lower end of the chain is at the foot of the steep when the upper end is attached to the full tub. Friction is caused by the chain dragging along the floor and in passing round the road-post as the tub is brought down the steep.

We may add that both mules and donkeys have been used underground instead of horseflesh, especially where the roadways are level and low, and the tubs small. They are both, however, difficult to manage, especially donkeys, owing to their

proverbial obstinacy, and are little used, if at all, in this country; but in the mines of the United States mules are extensively employed.

FLEUSS APPARATUS FOR BREATHING IN NOXIOUS GASES.

The Fleuss apparatus for breathing in noxious gases is a most useful appliance, which enables persons to remain under water or in vitiated air for limited periods of time.* It is shown in Figs. 427–445. Figs. 427 and 428 show in front and side view respectively the mask portion of the apparatus, by which the nose, mouth and ears of the person wearing it can be shut off from the surrounding air or gases. The mask is fitted with two pipes, A and B, one for the inlet of purified air to the interior of the mask, the other forming a passage for conducting the exhaled vitiated air to the purifying apparatus.

To secure the mask on the face, straps are used at the back of the head and also a bandage which is passed over the mask from C to D, and fastened under the wearer's chin, Fig. 428. In masks of more recent make, instead of the

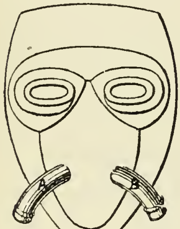


Fig. 427.

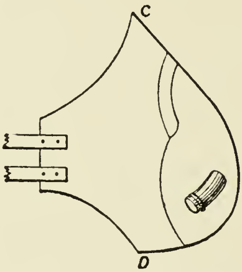


Fig. 428.

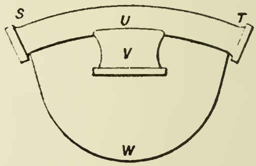


Fig. 445.

FLEUSS APPARATUS.

bandage, an india-rubber air-pipe is used, which, when in position round the mask, adapts itself to all the irregularities of the face and effectually makes a sufficiently tight joint. It is better that the person wearing the mask be without a beard.

Even to a beardless person the mask is not a comfortable arrangement, and instead of it, the "goggles" used by Denayrouse to protect the eyes may be substituted together with the apparatus shown in Fig. 445. It consists of a tube U, kept in position on the wearer by the band W. The two ends of the tube, S, T, serve the purpose of the tubes A and B in the mask. The whole face-piece is held by grasping the flat projection V by the lips and teeth. When using the mask the wearer is inconvenienced by perspiration and water which flood the mask after using it some time, and when using the more simple breathing appliance it is accompanied by an emission of saliva which is difficult for the wearer to get rid of.

The nose is in communication with the inlet tube and the mouth with the other, so that respiration proceeds by inhaling through the nose and exhaling through the mouth.

The apparatus for purifying the air is arranged in the form of a knapsack, and can be adjusted to the wearer in five seconds. Figs. 429, 430, 431, 432, 433, 434 and 435 show this. At the bottom is a strong metallic vessel E, about 6 inches in diameter and 16 inches long. This vessel is charged with compressed oxygen at a pressure of 250 lbs. to the square inch. Immediately above this

* See Transactions, North of England Institute of Mining Engineers, vol. xxxi., pp. 197—203.

vessel is a rectangular-shaped metallic case H. A vulcanite vessel M is fitted into the case H, as vulcanite resists the action of caustic soda.

This vessel (see Figs. 432, 433, and 434) has a perforated false bottom, and is divided into compartments by division plates. The central division plate extends from the bottom of the vessel to within a short distance of the top, whilst the other two divisional plates, one on either side of the central one, reach from the perforated false bottom to the top of the vessel. When made ready for use, the

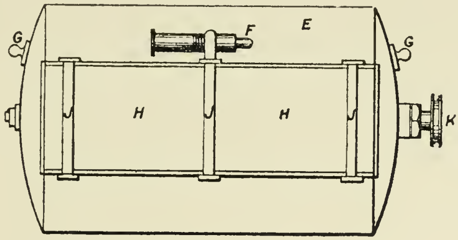


Fig. 429.

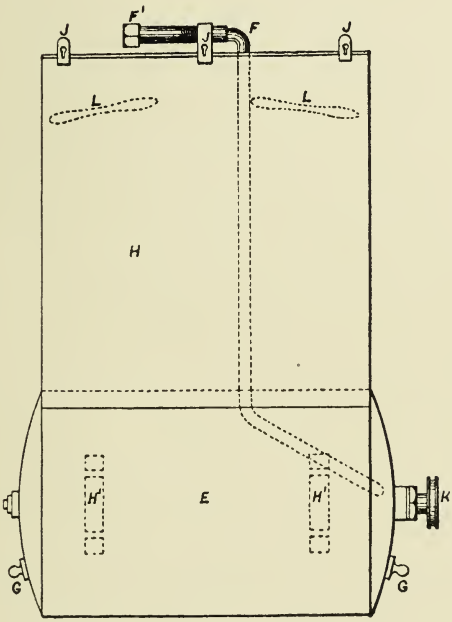


Fig. 430.

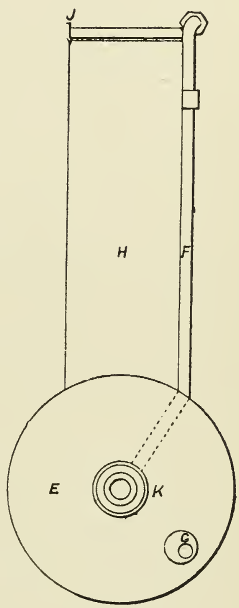


Fig. 431.

Fleuss Apparatus.

compartments of this vessel are filled with tow and caustic stick soda. The vessel is provided with a lid, made air-tight by an india-rubber washer placed between the lid and the vessel. Two pipes pass from the lid, the one marked N, Fig. 435, forming a passage through which the exhaled vitiated air is led into the end compartment, while by the other marked O, the air after coursing upward and downward through the compartments of the vessel M can pass back to the interior of the mask or breathing apparatus to be again inhaled.

The pipe O is made with a branch pipe O′, standing out from it, from the end

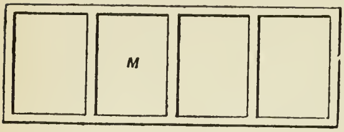


Fig. 432.

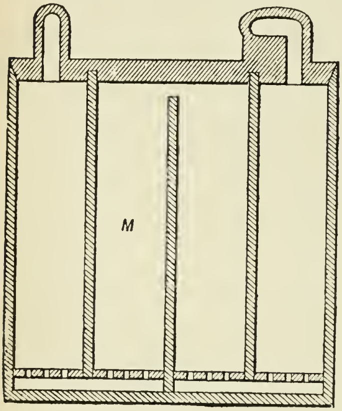


Fig. 433.

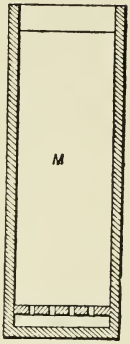


Fig 434.

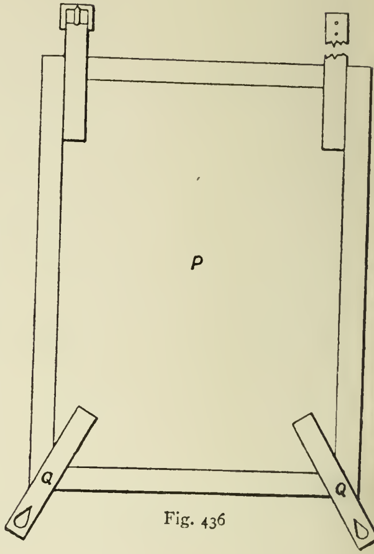


Fig. 436

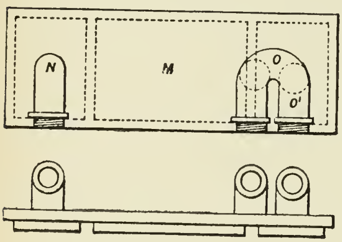


Fig. 435.

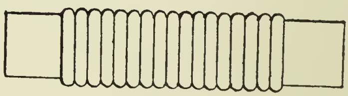


Fig. 437.

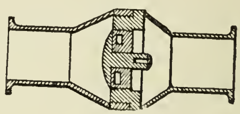


Fig. 438.

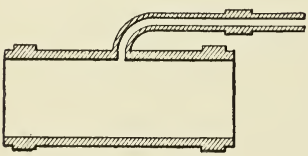
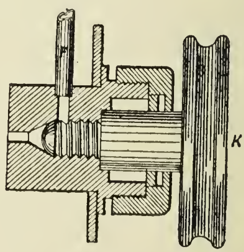


Fig. 439.



Fi . 440.

Fleuss Apparatus.

of which a flexible pipe is led to the interior of an air-bag P, Fig. 436. This bag acts as a flexible air reservoir, which expands when air is exhaled and contracts when air is again drawn from it into the lungs.

The inlet and outlet tubes on the mask are connected respectively to the inlet and outlet tubes on the lid of the vessel M by elastic tubes of india-rubber. Each elastic tube is provided at one end with a metal valve, see Fig. 438. The

inhaling valve opens towards the mask, the exhaling valve away from it. Each elastic tube is formed with corrugations, as shown at Fig. 437, so that it may readily stretch. The ends of the short tubes on the mask, as well as those on the lid of the vessel M and the ends of the valve-pieces, have each a projecting flange around them, so that when the ends of the connecting elastic tubes are simply stretched over these flanges, they are in sufficiently close contact to form air-tight joints.

To restore to the air its needed quantity of oxygen, a small pipe F, Figs. 429, 430, and 431, leads the oxygen from the metallic case E in which the store of

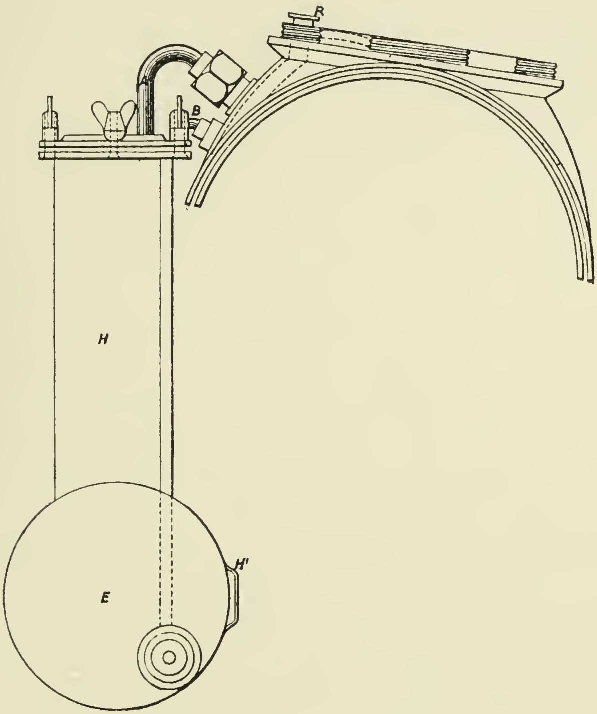


Fig. 441.—Fleuss Apparatus

oxygen, under pressure, is placed, and after passing through a flexible tube connected to it at F′, Fig. 430, is led into the flexible tube before alluded to, which is in connection with the air-bag. At the attachment of this smaller pipe with the larger, a short length of metal tube is used, as shown at Fig. 439.

The passage of oxygen from the vessel E to the air-bag is regulated by a valve K, shown more particularly in detail in Fig. 440. If the screw K be turned, the valve can be lifted, more or less, away from its seat, consequently leaving a larger, or smaller, passage through which the oxygen passes out from the vessel E to the small pipe F. The loops Q, Fig. 436, at the lower part of the air-bag, are passed over the studs G at the ends of the vessel E, Figs. 429, 430 and 431, when the apparatus is being adjusted to the wearer. The straps at the upper part of the air-bag, Fig. 436, form a loop when buckled together, which hangs over the shoulder of the wearer and is connected to the apparatus at L L, Fig. 430. The lid of the vessel M is held down, and the vessel kept

securely in the metallic case H, by bars J, passed across the top of the case, through eyes which project up from it as shown in Figs. 429, 430 and 431.

The apparatus, as just described, is a suitable arrangement for wearing in foul air, but when used for enabling persons in an ordinary diver's dress to work under water, without fresh air, a modification of the apparatus, as shown in Figs. 441 to 444, is used.

Fig. 441 is a side elevation of the ordinary metallic shoulder-piece of a diver's dress, with the apparatus connected to it. There is a clip-plate all round the edge of the shoulder-piece, by which the opening at the top of the diver's dress is clamped in the usual manner, and a tight joint made between them. Fig. 442 is a front elevation of the helmet, which is secured to the shoulder-piece and locked thereto by giving it a partial turn. A mask is worn over the nose and mouth of the wearer inside the helmet, a front and side view of which are shown in Figs. 443 and 444 respectively.

When the apparatus is used for deep water diving, the case H, containing the caustic stick soda, must be closed by a strong metallic cover, with metallic pipes

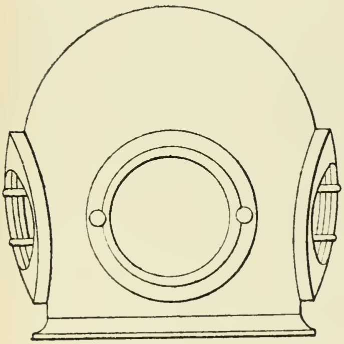


Fig. 442.

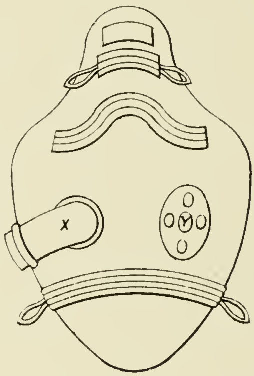


Fig. 443.

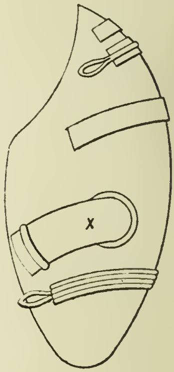


Fig. 444.

Fleuss Apparatus.

leading to and from it, and the vessel M, which holds the caustic soda, is formed with a flange round the top. Above the top of the vessel M is placed a strip of sheet india-rubber, and above this the metallic cover. The cover is kept securely in place by screws, as shown at Fig. 441. The pipes which take the foul air to, and conduct the purified air from, this vessel, are secured to the head piece, as shown at A, Fig. 441.

The purified air passes straight into the dress, which serves the purpose of the air-bag at Fig. 436, and the exhaled air is forced by the lungs through the pipe X, Fig. 443, and through a flexible tube to R, Fig. 441, from thence passing through the purifying vessel. A small valve is fixed on the mask at Y to prevent the exhaled air mixing with the purified air in the dress; and another valve is put on the outlet pipe, so as to prevent the exhaled air returning before being purified. A small pipe from the oxygen reservoir is also connected by a union to the shoulder-piece B, Fig. 441, and a continuation of the pipe leads into the interior of the helmet. The mask, or mouth-piece, Figs. 443 and 444, is not wanted to protect the eyes, and is consequently made smaller than the one shown at Figs. 427 and 428. H′, H′, Figs. 430 and 441, are metal loops formed on the exterior of the oxygen reservoir, through which a belt is passed and buckled round the waist of the person using the diving dress.

FLEUSS LAMP.

Accompanying the apparatus is a lamp which has been devised to burn when surrounded by gases which do not support combustion. The apparatus would be of no use in exploring the dark recesses of the mine without light, and this is obtained by means of the Fleuss lamp, shown in Fig. 446. In it, a metallic sphere N serves as a reservoir for compressed oxygen, and upon the sphere is fixed a spirit-lamp M, with a moveable pin D, for carrying a lime, and a moveable platinum tube G, capable of adjustment, for directing the stream of oxygen through the flame of the spirit-lamp on to the lime.

A tube O traverses the spirit reservoir of the lamp M, and the platinum tube G forms its upper extremity, while below it passes into the sphere N, which holds the oxygen and communicates with a jamb-cock P, capable of adjustment from without the sphere N, which enables the user to control and regulate the stream of oxygen for producing more or less light at pleasure. The spirit-lamp reservoir M forms part of the spherical oxygen reservoir, and is provided at its outer part with a screw thread and collar L, on which is screwed a double hood E, E′, the joint being made air-tight by means of a washer. The hood E consists of an elongated cylinder with domed top and flanged base and having within a screw-ring K for attaching to, or detaching from the screw thread and collar L, on the spirit-lamp M. To the flanged base is soldered or brazed a somewhat similar cylinder E′, of greater diameter, so as to form an annular space between the two cylinders, which is filled with water. The cylinder E is provided with a glass disc C facing the flame of the lamp, and the cylinder E′ similarly has a glass disc or bull's-eye B, by which means the rays of light from the interior of the lamp pass through the water contained by the two cylinders to the exterior. The products of combustion are carried into the space filled with water through a sensitive valve H, fitted into the cylinder E near the base, and pass outwards through a valve A in the centre of the dome above the water level to the exterior of the lamp. The outer cylinder E′ is provided with a suitable handle for carrying the lamp. A cap J is fitted to it, which, when removed, exposes the valve H in the inner cylinder and facilitates its renewal. The spherical oxygen reservoir N is fitted with a suitable connection R, through which is admitted a fresh charge of compressed oxygen when the reservoir has been exhausted. A metallic ring S, attached to the lower portion of the globe, forms a base on which the lamp will stand, and lamps used for submarine operations have a weight enclosed within this ring. The object of the weight is to counterbalance the buoyancy of the lamp. In recent forms of the lamp a worm and screw motion is added to the valve P, so as to regulate the admission of oxygen to the greatest nicety.

The oxygen is supplied by the patentees in wrought-iron bottles, 6½ inches outside diameter, 3 feet 3 inches long and ¼ inch thick, 16 hours supply tested up to 1,000 lbs. per inch, and filled with oxygen at about 600 lbs. to the inch for £5 5*s*. each, £4 10*s*. being for the vessel and 15*s*. for the oxygen. The contents of these bottles can be conveyed to the lamp and breathing reservoir in less than a minute.

The cost of the apparatus for breathing in foul air is about £20, and of the lamp about £14. For exploring purposes it is most useful, and in underground roadways of 3 feet 6 inches high or upwards, travelling with it is not difficult. It weighs about 28 lbs., however, and is too cumbersome to admit of the wearer ridding, timbering, or doing similar work. A man accustomed to the apparatus may remain 3 or 4 hours in it while surrounded by unbreathable gases with one charge of oxygen, but if he exerts himself violently or is nervous or excited the supply will be exhausted much sooner.

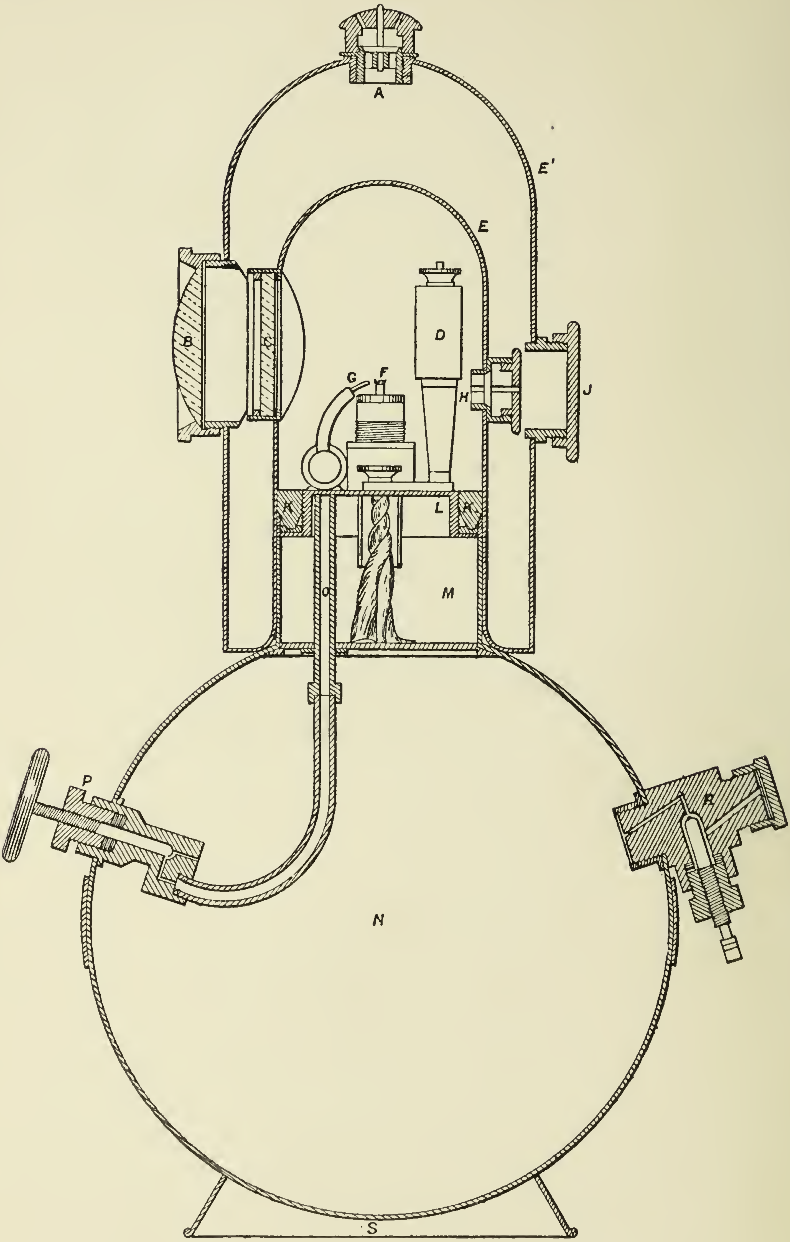


Fig. 446.—The Fleuss Lamp.

The supply of oxygen being under the control of the wearer may be urged as an objection to the apparatus. If he become nervous and supply himself too freely he will exhaust the store before it is safe to do so; no other inconvenience would arise, as an overdose of oxygen is not injurious. This objection would be

removed if some regulator could be attached which would maintain a continuous and regular supply of oxygen.

The lamp will burn about 4 hours. When men enter the mine, with the apparatus fitted on, they proceed as far as possible with safety and comfort to themselves without putting the breathing appliance to their mouths. At the point where it becomes necessary to do so a saving of time may be effected by leaving there a store of bottles containing compressed oxygen, so that on returning to it the apparatus may be replenished.

There should always be 3 persons or more together when exploring in dangerous gases, and they should withdraw at once if any one of the number get into difficulty.

At Killingworth the apparatus was used for the purpose of saving life, and there two men carried out a fainting man while the third carried the lamps. After the Seaham Colliery explosion on Sept. 8, 1880, resulting in 168 deaths, the Fleuss apparatus was used for exploring purposes.

As an instance of its use under water, a case at the Severn Tunnel may be mentioned. The making of this tunnel was beset with great difficulties. When the headings on the opposite sides of the river had approached to within 138 yards

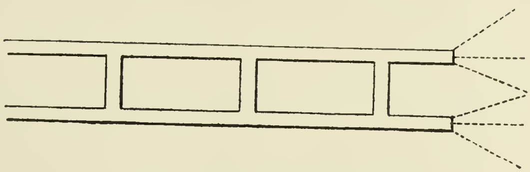


Fig. 447.—Boring Exploring Places.

of joining each other, a large spring was tapped. In order to master it, new shafts were sunk on both sides of the spring and by using powerful pumps in these the head of water was gradually lowered.

Besides the water from the large spring a considerable quantity came from the river heading through a flood door. To get rid of this for a time became of much importance and a noted diver was engaged to make an attempt to close the flood door. The man made a most plucky attempt to get to it in his ordinary diving dress; but his air pipe floated so hard against the rough roof of the heading that although he got within 70 yards of the door, he was obliged to turn back and had extreme difficulty in retracing his steps.

Fleuss, the inventor of the apparatus described, was then invited down to close the door. He went down the shaft in company with Lambert, the skilled diver who had previously failed to shut the door, to the mouth of the heading, but not liking the appearances presented to his view there he came up again and declined to go further. Lambert then put on the Fleuss apparatus, and after one failure succeeded in closing the door.

EXPLORING FOR WATER.

In approaching, from the dip, old wastes containing water, it is necessary to drive a single place or a pair of places in the direction of the waste and to bore horizontally in the coal. The chisel used for this purpose is usually $1\frac{1}{2}$ inches in diameter. In most cases one exploring drift is sufficient, but if two are required —one as an intake and the other the return—and both are within the statutory distance of 40 yards from the old workings, each drift should have three bore holes, one front hole and one flank hole on each side, the latter being at an angle of about 45° with the former, see Fig. 447, and bored at regular distances, say every 4 or 5 yards. The length of the front hole will be subject to circumstances, depend-

ing upon the nature of the coal and the head of water in the waste. The Mines Act says that the drift shall not exceed 8 feet in width at any point within 40 yards of the dangerous accumulation, and there shall be constantly kept at a sufficient distance, not being less than 5 yards in advance, at least one bore hole near the centre of the working and sufficient flank holes on each side. If 10 yards of barrier be desired, the front hole should be 11 or 12 yards, and then 1 or 2 yards of coal worked off, the hole being again bored the same distance after each such removal. A few fir plugs from 4 to 6 feet long (pointed, tapered, and hooped with iron at the head, and; if the pressure is likely to be very great, having cross-pieces attached so that the force of 2 or 3 men and a heavy hammer could be applied for entering and driving them) should always be ready at hand so as to stop the flow of water as soon as tapped; it can afterwards be allowed to run at convenient times. Suppose 5 yards to be the minimum length of hole, and 20 fathoms the minimum pressure, the length of hole should be increased 1 yard for every 10 fathoms. As the boreholes approach the waste the water will probably ooze through to the borehole and give some indication of the proximity to the waste, before actually holing into it. Mr. Greenwell says that the quantity of water which such boreholes will run per minute may be calculated by the rule given in answer 191, Chapter XV., where an example is worked out.

UNDERGROUND DAMS.

It is sometimes necessary to put in dams in the underground workings; for instance, exploring parties in narrow places may meet with large quantities of water which it is desirable to keep back, or the necessity may arise from other causes. In selecting the situation for a dam, care must be taken to choose one free from slips and faults of all description, and it should be prepared, if this be practicable, with the pick, and no explosives used, because the shots shake the coal or stone. The sides, top, and bottom must be dressed perfectly smooth. Wood or brick may be used, the former being preferable, because the least yielding of the masonry abutments causes fracture and breakage. The requirements of a dam are that it shall be perfectly water-tight, and be able to resist the pressure brought to bear upon it. Masonry dams consist of two or more concentric arches placed several feet apart, the space between them being filled up with clay and well rammed. Sound, well seasoned oak is the best material for wood dams. They are used in pieces from 3 to 8 feet in length (depending upon the pressure which the dam is required to resist), square, and tapered, and the radius of the inner circle should be from 18 to 30 feet. They are laid down in rows beside each other, and one upon another, with their larger ends towards the water. They are carefully prepared on the surface, and to ensure fitting accurately they are built together there, and each piece numbered before going into the mine. To allow for the pressure pushing the dam forward, it is advisable that its seat be continued of its tapering form a few feet. Figs. 448 and 449 will assist in explaining the dam.

The sides, bottom and top having been accurately dressed, a layer of tarred flannel should be laid next to the coal or stone, and the pieces of wood built up. It is necessary to insert three metal pipes as the building proceeds; one, marked A on the sketch, about a foot from the bottom, and of a size to allow the water to run through, or if the quantity of water is very large two such pipes may be inserted. A second pipe B, about 2 feet from the bottom and 18 inches in diameter, is laid, to allow of the men passing through during the building and wedging of the dam. It must be remembered that it is necessary to have the wedging done on the side from which the pressure comes, viz., on the inside of the dam. Another pipe C, about an inch in diameter, is placed near the roof. The water

is conveyed by boxes to the water pipe or pipes A in the dam, and the pieces having all been built up, the wedging is proceeded with from the inside. Fir wedges, 12 inches long by 3 inches broad and an inch thick at the head, are first

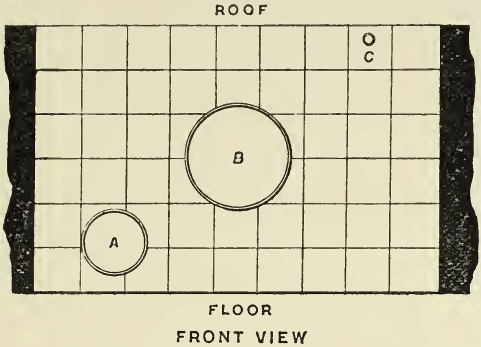


Fig. 448.

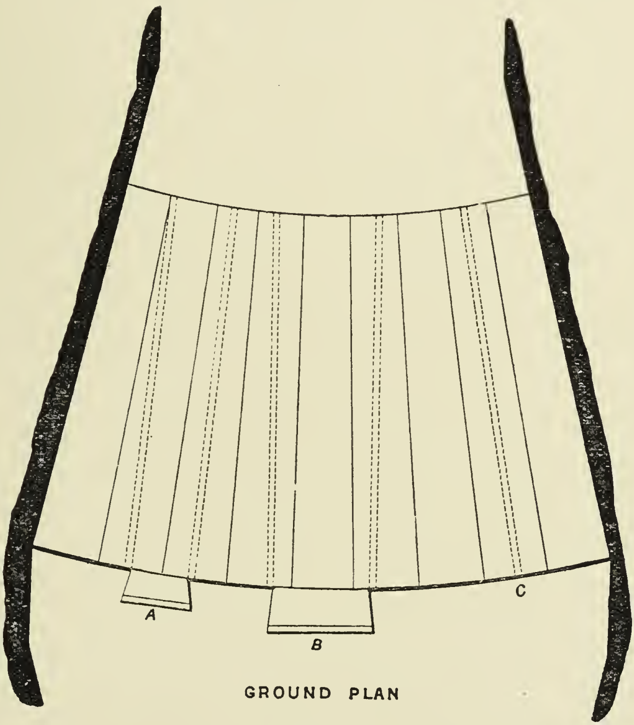


Fig. 449.

UNDERGROUND DAM.

driven in, and after these have been driven at all the joints and round the pipes, smaller wedges of oak may be driven, an iron chisel being used to prepare places for their insertion. When no more wooden wedges can be got in a few steel wedges may be made to enter, more especially between the wood and the stone or coal. After the wedging is completed, the workmen drive a plug of wood

which has been prepared for the purpose into the water pipe A, but if practicable the pipe C should be continued by means of iron pipes to such a level as will outset the water, otherwise it must be plugged. The workmen then retire through the pipe B, and a plug which has been prepared and carried in before the erection of the dam, and which is covered near its larger end with vulcanised india-rubber so as to ensure a water-tight joint with the pipe, is drawn in by means of a rope, and tightened by attaching the rope to a lever, or a windlass. The subsequent pressure of the water forces in the plug still more firmly. A dam of this description will resist a pressure of from 50 to 100 fathoms of water. The pressure the dam has to resist will be found by the following rule

H = head of water in feet.
P = pressure in lbs. per square foot = $62 \cdot 4$ H.
p = pressure in lbs. per square inch = $\cdot 4\dot{3}$ H.

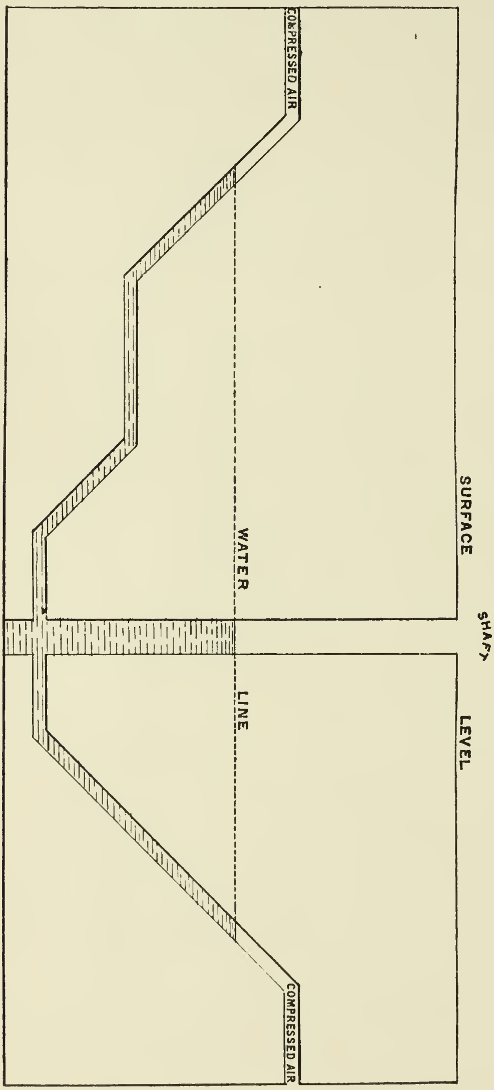


Fig. 450.—Sketch to Illustrate the Phenomenon of a Water-blast.

WATER-BLASTS.

Sometimes water accumulates in workings temporarily abandoned, and reaches a considerable height in the shaft, and in such a case, after the opening into the seam has been "drowned," thereby excluding the passage of air, the air left in the rise workings will become compressed as the water rises in the shaft, see Fig. 450. If gas be given off from the coal, the pressure of the gas will also be increased, and both air and gas are thus pent up. In taking out the water on resuming work at the colliery, it is quite likely that a sudden rush of air and gas may take place, owing to the elasticity of these bodies, and when this happens, the air will force itself through the water with great violence and noise, and the level of the water in the shaft and workings will fall suddenly—it may be some fathoms—and produce what is called a "water-blast." Great care is therefore needed in unwatering a mine after inundation, for several instances are recorded where water-blasts on a large scale have occurred.

UNDERGROUND FIRES.

Undergound fires are of frequent occurrence in mining operations, and when they occur are exceedingly difficult to deal with. The heat itself is intense, and the air near the fire is vitiated by the products of the combustion, and if firedamp exist, there is a constant danger of an explosion added to the already existing evil.

Fires are frequent in the workings and wastes of some mines, and where naked lights are used their occurrence is to be expected sooner or later, for there is generally plenty of inflammable material ready. They may arise from such causes as a light being set to a body of dry material, in contact with the coal, such as old props, canvas or deal bratticing, doors, &c., or sparks from an underground boiler or furnace, or an explosion of firedamp, or of a shot. A frequent cause is spontaneous combustion. The fire usually extends towards the fresh air current entering the mine.

If a seam of coal contain iron pyrites, and heaps of small pyritous coal lie about exposed to a moist atmosphere, the conditions are favourable to spontaneous combustion, because decomposition sets in, attended with a liberation of heat. This heat not being allowed to escape, or to escape but slowly, combustion of the sulphur follows.

Coal seams which have no iron pyrites are also subject, but in a lesser degree, to spontaneous combustion, for when heaps of small coal are exposed to a moist atmosphere, oxidation takes place, heat is generated, and, under certain circumstances, combustion ensues. The nature of the roof affects the spontaneous combustion of coal. Beneath a sandstone roof spontaneous combustion is unlikely to occur, because the heat escapes as fast as it is generated. With a soft shale roof, which is impervious to the gases formed, the heat is confined, unless there are fissures which allow the gases to escape.

As the presence underground of heaps of small coal is necessary to spontaneous combustion, in order to avoid fires from this cause, all small coal should be sent out to the surface if this be practicable. Another plan is to prevent the air from coming in contact with the small coal in the wastes by erecting air-tight barriers. Another method, and probably the most effective, is to send such a volume of air to the dangerous masses of coal as to keep their temperature down.

To extinguish an underground fire, the first procedure is to isolate that portion of workings where the fire exists. By a reference to the colliery plan, a line is decided upon which has the fewest number of openings crossing it, and air-tight stoppings or barriers must be erected in each of these places, and as time is of great consequence, these must be proceeded with without delay. If the air could be effectually kept from the fire in this way, it would soon cease, but it is almost impossible to close all crevices, and it has been found where nothing more was done that, although the fierceness of the fire ceased at the time, directly operations were begun again and the air admitted, the smouldering fire burst out afresh. This being so, after the barriers are erected and the intensity of the fire stopped, recourse is had to other means to finally extinguish the fire, if such means are available.

The most effectual plan is by flooding the mine, which may be done by stopping the pumps and allowing the water to rise, or by sending down water from the surface. This is, however, a costly method of putting out a fire, for the water has to be pumped out again after the fire has ceased, and generally much damage is done to the roads and workings by flooding. This is especially the case where the floor or roof is softish or of a clayey nature.

Another plan is to produce carbonic acid gas in large quantities and direct it by pipes on to the fire. Carbonic anhydride may be sent to any portion of the mine—to the extreme rise for instance—which could not be reached by water except by flooding the whole mine.

It is sometimes impossible even to enter the mine after the coal has been set on fire following an explosion of firedamp. In this case the shafts themselves must be sealed. For this purpose a scaffold is fixed a few feet down the shaft. Or it may be suspended from balks of timber laid across the top by means of stout chains, and it should fit truly round the shaft; a quantity of plastic clay is then thrown on the scaffold, and a stratum of water may be placed on the top of this to ensure all being air-tight. Cast-iron pipes of 6 inches diameter may be placed through the scaffold before the clay is thrown down, reaching to the surface, and furnished there with valves opening outwards only, so as to admit of after observations, such as the analysing of escaping gases, or testing them with the safety lamp. An inch gas-pipe may also be placed through the scaffold, reaching upwards to the surface, and furnished with stop cocks, so that a water gauge or pressure gauge may be applied and the pressure inwards or outwards ascertained.

TESTING THE ROOF.

The safety of the roof is judged of by general appearances and the sound produced on tapping it with a small hammer or other suitable article. If it looks solid and the sound indicates that it is so, the roof is usually safe, but this alone should not be implicitly relied on; the lamp or candle should be held up to the roof, and a careful scrutiny be made for joints or cracks. The sound may sometimes appear to show a stone to be solid when it is not so, the large size of the stone stopping the hollow sound.

If a hollow sound be emitted when the roof is struck, the stone is unsafe and should be either taken down or timber set up under it. The sides must also be examined, and this is usually done without sounding, by carefully examining them with the aid of the lamp or candle.

FAULTS, AND METHODS OF DEALING WITH THEM.

Faults are frequently met with in mining operations. When the workings meet with interruptions which have not been proved elsewhere, to ascertain if the fault is a rise or dip one, observe the angle which the leader of the slip makes with the floor. If the angle be obtuse, as shown in Fig. 451, the leader will have appeared in the roof first, and the probability is that the coal is thrown down on the other side of the fault. If, on the other hand, the angle be acute, as shown in Fig. 452, the leader will have appeared in the floor first, and the probability is that the coal is thrown up on the other side of the fault. These remarks hold good generally, but in the case of overlap faults, which are prevalent in some districts, the reverse obtains, as seen in Fig 453. Frequently the rate of dip is considerably altered as the workings on a seam of coal approach a fault, and this irregularity indicates the coming disturbance.

Rolls in the coal seams are not, strictly speaking, faults, as there is no interruption in the continuity of the seam, but the coal describes an abrupt curve rising rapidly from the beginning of the roll in a curved line to its summit and as rapidly dipping back to the end of the roll, from which the seam continues in its normal condition, or the roll may be curved in the opposite direction, and its lowest point be considerably below the level of the seam where it resumes its normal condition.

Sometimes the continuity of a coal seam is broken without any disturbance in the level of the two ends of the seam, which are separated by a mass of unproductive material, in Somersetshire called "dead ground." At others the two ends of the seam, instead of terminating abruptly against the barren ground, will

taper away in wedge-shaped pieces of coal against it, and this kind of fault is called a "nip out" or "want."

After proving a fault and ascertaining the amount of dislocation, unless large, a permanent road should be made through it. In a perfectly level seam, and the fault a downthrow or "dipper," the bottom should be taken up from a point a few yards on the out-bye side of the fault, and the road continued through it at a regular gradient suitable for haulage, say, of 2 or 3 inches to the yard, till the seam is cut on the other side of the fault. If the fault is an upthrow or "riser," the top should be taken down and the coal reached by an easy rising road. If a dip fault cut the coal off in the water-levels, where the seam of coal has a certain

Fig. 451.—Downthrow Fault.

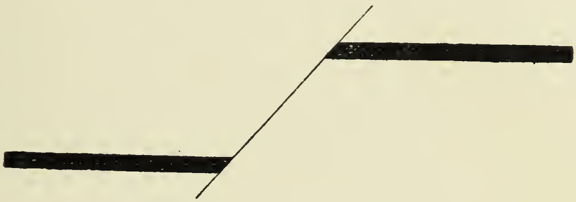


Fig. 452.—Upthrow Fault.

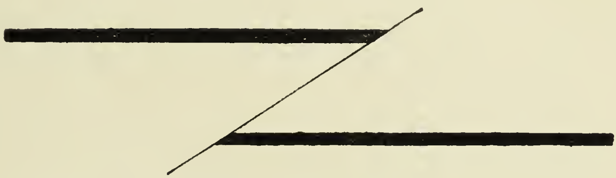


Fig. 453.—Overlap Fault.

rise, and it is desired to keep strictly to the water-level course, the water-levels must be turned in the direction of the rise, and by keeping truly water-level, but with the drift turned at a suitable angle, the coal will be cut on the other side of the fault. If, however, the fault be an upthrow, and it is important not to "lose level," the water-levels should be given a "down-hill" turn, so as to cut the coal on the other side of the fault, and yet keep the water-level course. Examples have been worked out at the end of Chapter VII. in explanation of this, see Answers 46, 47 and 49.

STEAM INDICATORS.

The original indicator was invented by Watt, for the purpose of accurately ascertaining the internal condition of the steam engine, the state of the vacuum, the amount and variations in the pressure of steam at every point of the stroke, the cushioning, the condition of the slides, whether the ports are opened and closed at the proper time, &c., in his engines.

Watt's indicator, in a form for tracing out a complete diagram, is shown in Fig. 454. It consists of a cylinder L, about 1 inch in diameter and 6 inches long, fitted accurately with a solid piston P. At the bottom, the cylinder is fitted with a steam-cock K, which is screwed into an opening made in the cylinder-cover, or into an opening in the cylinder of the engine itself, close to the end. At the top, the cylinder is open, so that the upper side of the piston P is subject to atmospheric pressure. The piston is fitted with a small rod on its upper side, which carries at one end a pencil R, so as to mark on a board moving to and fro horizontally in the frame A B C D. The board receives its motion by means of a cord, shown in the Fig., which is fastened to some reciprocating part of the engine, the period of whose motion is identical with that of the engine piston. The weight M at the other end of the cord causes the return motion of the board. The spiral spring N controls the vertical motion of the piston.

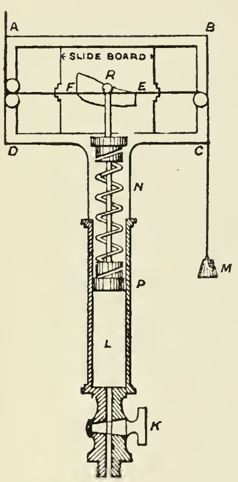


Fig. 454.—Watt's Indicator.

As first introduced by Watt, there was no sliding board to the instrument, but the pencil moved in vertical direction in front of a graduated scale. By this means the pressure of steam in the cylinder, or the amount of vacuum, could be ascertained. The addition of the sliding board, however, enables a complete diagram to be traced on it, by means of which the steam-pressure and vacuum at any point of the stroke is obtained.

When the instrument is screwed into the steam-engine cylinder-cover, the string passing upwards at A is attached to some moving part of the mechanism so that the board receives a motion corresponding to the engine piston, but with a reduced travel. If the board be now moved to and fro, the pencil traces the horizontal line E F, technically called the *atmospheric line*. On turning the cock, K, steam is admitted from the engine-cylinder into the lower end of the indicator-cylinder, and presses upwards against the piston P. When the pressure of the steam balances that of the external atmosphere the piston remains at rest. If the steam-pressure (or uncondensed vapour below the piston) be either greater or less than that of the atmosphere, the pencil will rise or fall, and the curve drawn will be the result of combining the motion of the pencil with that of the board.

The steam indicator invented by Watt has been much improved, but the general principle remains the same. Perhaps the best known and most frequently used at collieries is *Richards's*, which will be understood on reference to Fig. 455. *c* is a screw for fastening the indicator to the cylinder. The handle on sketch is to open the connection between the cylinder of the engine and the indicator, and by means of which the steam is admitted under the piston *d*, working in the indicator cylinder *fm*, which has the end *m* always open to the atmosphere. The piston *d*, with its rod *e* of the indicator, are shown in dotted lines, the former being half a square inch in sectional area. The dotted slanting lines show the spring which keeps the piston down, and against which the steam has to act in forcing up the piston *d*. A complete set of these springs and scales corresponding thereto, suitable for working at different pressures, are usually supplied with the instrument. *fr* is the barrel round which the paper is wrapped, the paper being made fast by two clips. Inside this barrel is a spring, the object of which is to effect the return of the drum, after it has been rotated by the string.

Although the movement of the drum has no connection with that of the indicator piston, when attached to a steam cylinder for use, both are made to move simultaneously, so that when the barrel has moved nearly round once, during which the piston goes up, the force of the spring causes it to return, as the indicator piston goes down. The graduated scale is to measure the pressure of steam and the vacuum, but it is not marked on modern indicators. A piece of whipcord passes round the pulley *gs*, which gives motion to the barrel. While the piston of the engine moves several feet, that of the indicator moves up less than an inch, and the barrel has to move round four or five inches in the same time. Motion is given to the barrel from the piston crosshead, and levers are used to

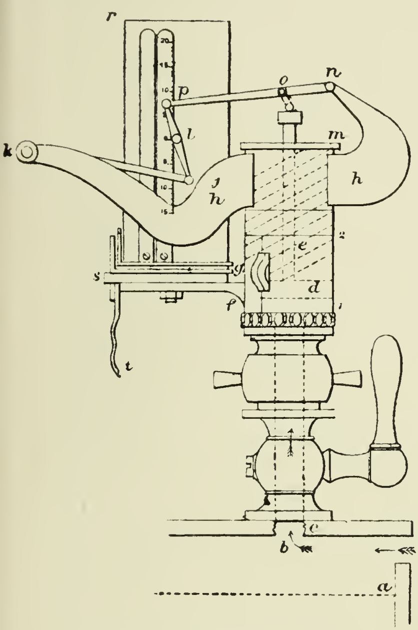


Fig. 455.—RICHARD S'S INDICATOR.

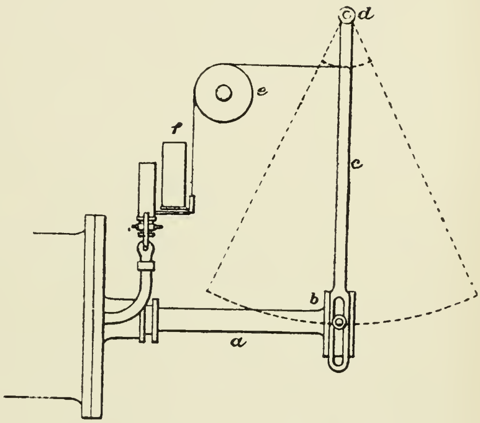


Fig. 456.—PULLEY AND LEVER INDICATOR GEAR—OVER MOTION.

reduce this motion. If the length of the diagram be three inches, and the length of stroke three feet, we have to proportion the levers as 3 : 36, or as 1 : 12, and the required motion is obtained. The indicator barrel is moved round by the string which is attached to its proper relative position of the lever, actuating the pulley *gs*, and with the pulley, the barrel. The arm *hh* carries the parallel motion *kjpn*, the pencil being at *l*. By means of this parallel motion the stroke of the indicator piston is, say, from 1 to 2 on the sketch but the pencil is required to have more motion, say from the lower 15 to 25 on the scale, and this it gets through the application of the parallel motion. This is readily seen, for the end of the indicator piston rod is attached to the lever *pn* at *o*, and the end *n* being fixed, the motion of the indicator is multiplied in the proportion of *no* to *op*. In Richards's indicator this multiplier is about 3·5, and the motion being thus increased, the pencil indicates on an enlarged scale the least variation of pressure or action.

There are different methods of arranging the lever or levers to the crosshead or piston-rod, sometimes two levers being used, sometimes one, and these may be

applied either with under motion or over motion. Fig. 456 shows the gear with over motion.

The indicator is shown at *f*. The lever *c* is hung on a pin, *d*, supported by a bracket, or anything equally applicable. It is looped at its other extremity, so as to allow for the travel of the pin on the crosshead, *b*. The barrel of the indicator, *f*, derives its motion from the correct point on the lever, *c*, being connected by a cord passing quarter round the pulley *e*, and then continued to the pulley on the barrel.

Supposing now the indicator to be attached in this way to a vertical condensing engine, its action is as follows. As soon as the attachment is completed, the lever at the crosshead causes the barrel of the indicator to move from right to left, and a straight horizontal line will be drawn by the pencil. Generally, the pencil is allowed to mark this line several times, and it is called the atmospheric line, because it coincides with the atmospheric pressure: all parts of the diagram above that line show the pressure above the atmosphere, and all parts below it show the vacuum, so that the top part of the diagram is called the "steam," and the bottom the "vacuum." It has been stated that if only the barrel be made to move, a horizontal line is traced, but if now the motion of the barrel be stayed, and the steam admitted to the indicator by turning the handle for the purpose, the pencil would be driven straight up, or a vertical line would be traced. When both the barrel and the indicator piston move together, the result is a line compounded of the two motions.

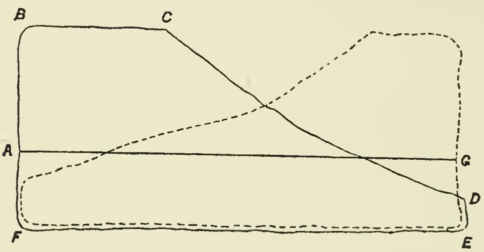


Fig. 457.—Indicator Diagram.

After the indicator has been attached to the crosshead at one end of the cylinder, say the top, having marked the atmospheric line a few times, the handle of the indicator, which admits the steam to it, is turned at the instant the top port opens, the piston of the engine being at the top of its stroke. The moment the steam enters the cylinder it drives the piston down in the direction of *a* on the indicator sketch, Fig. 455, and also enters the indicator in the direction of *b*, forcing the piston of the indicator up. This causes the vertical line AB, Figure 457, to be drawn on the paper. The steam continues entering at its normal pressure, the piston of the engine goes down, and, so long as the pressure remains the same, the pencil of the indicator remains at the same height, and the barrel moves round, causing the line BC, Fig. 457, to be drawn.

When the pencil gets to C, the valve has closed the port, and the steam is left to expand; as it expands the pressure decreases, becoming less and less and the pencil falls gradually lower and lower to D. When it gets to D, the upper port is opened to the exhaust, the steam rushes out in a contrary direction to the arrows on Fig. 455, and the pencil falls to E, Fig. 457. There is now a vacuum above the piston of the engine and below that of the indicator and the vacuum line E F is traced. When the pencil gets to F the piston has arrived at the end of its stroke, cushioning takes place and the pencil rises at once to A.

Similarly the dotted lines show a diagram from the other side of the cylinder, so that each figure represents the action of the indicator through an up-and-down stroke or a complete revolution of the crank.

As illustrating the use to be made of the indicator diagram, suppose Fig. 458 to have been taken. The first thing to do is to divide the length of the figure

into 10 equal divisions and then to set off half of one space from each extremity and arrange the remainder equi-distant. Lines are drawn at right angles with the atmospheric line from each intersection or divisional point, then with the scale of the diagram each ordinate is measured and figured above and below the atmospheric line. The total sum of each set of ordinates is then obtained by simply adding the several lengths together, and the mean is got by dividing the total by the number of ordinates—in this case 10. In Fig. 458 the mean pressure of the steam is 15·575 lbs. on the square inch, and the vacuum obtained is equal to an atmospheric pressure of 9·69 lbs. on the square inch. The effective pressure on the piston then is $15{\cdot}575 + 9{\cdot}69 = 25{\cdot}265$ lbs. per square inch, and the horse-power of the engine may be found from this, knowing also the length of stroke and the number of strokes the engine is going per minute. It will be observed that the remarks on Fig. 458, R 110, S $27\frac{1}{2}$, V 26, mean that the engine is going 110 revolutions per minute with a steam pressure in the boiler of $27\frac{1}{2}$ lbs. and the vacuum gauge marks 26 inches or 13 lbs. pressure. It will be noticed that the highest record of full supply of steam in the cylinder is 24·2 lbs. showing a loss due to friction and radiation in passing from the boiler to the cylinder, also that the difference in the vacuum pressure is owing to the temperature in the cylinder being higher than in the exhaust steam pipe at the condenser end.

To be strictly accurate in working horse-power of engines a diagram should be taken on both sides of the piston, even where the action of the steam on the one side is repeated on the other, and a mean of the two diagrams adopted as representing the effective steam pressure, but for the sake of clearness the method is here shown with a single diagram.

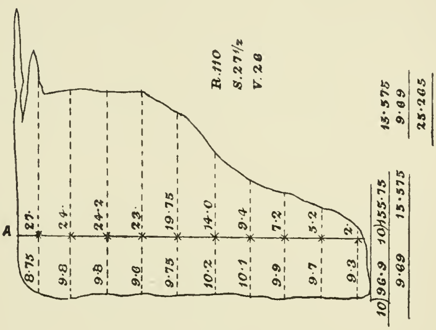


Fig. 458.—Indicator Diagram.

In diagrams taken from non-condensing engines the line traced will not, of course, at any point descend below the atmospheric line, but will in fact be above it owing to the back pressure of steam on the other side of the piston. Therefore, in measuring the ordinates on a diagram obtained from a non-condensing engine, measure with the scale from the atmospheric line to the upper line traced on the diagram and also from the atmospheric line to the lower line of the diagram. Having obtained the average of each set of ordinates, subtract the one from the other, that is deduct the average back pressure from the full pressure to obtain the average effective pressure. The average back pressure is seldom less than 3 lbs. even in good engines.

Goodeve, in his *Text Book of the Steam Engines*, thus writes of the indicator diagram of a single-acting engine :—

"In the single-acting engine two diagrams must be taken, one from the top and the other from the bottom of the cylinder. These diagrams are quite unlike in form, for the action during the down-stroke is not repeated during the up-stroke as in a double-acting engine, and our first task will be to comprehend the reasons of the particular conformation observed. For this purpose reference is made to a diagram taken from a Cornish pumping engine, having a cylinder 70 inches in diameter and making 4 strokes per minute, under a mean pressure of 15·1 lbs. per square inch. The figure is

reduced from one on a larger scale, so that the indicator spring would extend one inch on the reduced diagram for a steam pressure of 40 lbs. per square inch.

"One card is taken from the top and the other from the bottom of the cylinder and each must be interpreted in its turn.

"As far as the upper card, Fig. 459, is concerned, that figure indicates the admission and cut-off steam, together with the opening of the equilibrium valve, which corresponds to imperfect condensation in our normal diagram. The lower card has reference to the state of things below the piston where the equilibrium and exhaust valves are opened consecutively.

"Beginning at the point A, with the piston at rest at the top of the cylinder, we note that the pressure rises until the down-stroke commences, when the steam line B C D is traced out. The portion B C is horizontal and the cut-off takes place at C. It is common for the steam line B C to drop considerably before the cut-off begins, especially in large engines. The line D E indicates that the equilibrium valve is opened, and that the steam pressure has fallen somewhat during the circulation which takes place. At the point E the equilibrium valve is closed and compression or cushioning begins, just as in a double-acting engine. At the point A the piston is coming to rest, and there is a drop in the curve which is often much more marked than in the present example, and which indicates loss of pressure before the down-stroke begins. Such loss would

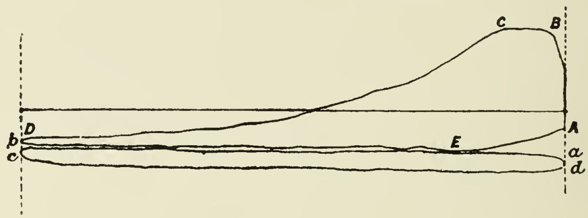


Fig. 459.—Indicator Diagram.

be due to leakage of the compressed steam round the circumference of the piston, or perhaps to loss of heat.

"As to the lower card, the nearly horizontal line, *b a*, shows that the equilibrium valve is opened. When compression begins at E, above the piston, expansion will also begin to much less extent below it, and there will be a slight drop towards the end of *b a*. Otherwise, the lines D E and *b a* nearly coincide, and would do so absolutely, if there were no disturbing causes at work; but the diagram shows some difference of pressure at the two ends of the cylinder when the equilibrium valve is open.

"With regard to work done, the piston is driven down by the steam from above it, as opposed to the back pressure of the exhausted space underneath, and that part of the action is fully determined by comparison of the lines B C D and *d c*. But the whole work done by the steam in the double stroke is, according to our principles, obtained by a careful measurement of the areas of the enclosed figures.

"At first sight, the student might imagine that the horse-power may be calculated by simply noting the pressures indicated by the steam and exhaust-lines, the cutting away of any part of the intermediate area—as by compression or by want of coincidence of the lines D E and *b a*—affecting only the up-stroke when the weight of the pump-rods is the moving force. But a little consideration will show that such a notion is erroneous, and that the compression of steam in the up-stroke, and the resistance to the motion of the piston due to inequality of pressure when the equilibrium valve is open, must be deducted from

the total efficiency. The steam opposes the piston in its ascent to some degree, and this gives rise to negative work, which must be deducted from the positive work accomplished in the down-stroke. In other words, during the down-stroke the steam does the work, and during the up-stroke work is done upon the steam.

"It follows, therefore, that the portion of unoccupied space between the two intermediate horizontal lines is a veritable subtraction from the efficiency of the agent.

"We pass on to calculate the horse-power in the case of a single-acting pumping-engine, having a cylinder 112 inches in diameter, with a stroke 9·166 feet, and making 7·5 strokes per minute.

"Referring to the diagram, Fig. 460, where the steam pressures are noted, and taking each group of numbers in order, there is, above the atmospheric line, a series amounting in all to 56·5. Below the atmospheric line the first series amounts to 48·5, and the second series gives 39·3.

"Hence the mean pressure of steam $= \frac{1}{10}\,(56{\cdot}5 + 48{\cdot}5 + 39{\cdot}3) = 14{\cdot}43$,

$$\therefore \text{H.-P.} = \frac{14{\cdot}43 \times 3{\cdot}14159 \times 56 \times 56 \times 9{\cdot}166 \times 7{\cdot}5}{33{,}000} = 296{\cdot}5.\text{"}$$

In engines working under a varying load, such as winding-engines, it is useful to have diagrams taken of every stroke made during such variation of load, and for this purpose an arrangement of indicator capable of taking continuous diagrams is now used.

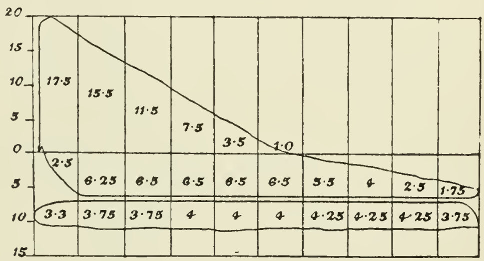


Fig. 460.—Indicator Diagram.

In the improved Richards Indicator made by Messrs. Schäffer and Budenberg of 1, Southgate, Deansgate, Manchester, a screw arrangement can be supplied for raising the paper drum of the indicator by hand for the purpose of taking a number of diagrams in succession. This arrangement is very suitable for colliery winding or hauling engines as a paper of diagrams can be obtained throughout one wind, arranged in the order of taking on the paper. These indicators are very carefully made and each instrument is thoroughly tested before being sent out. The tension of the spring in the drum can be regulated to suit the speed of the engine, by loosening the upper nut on the drum spindle and turning the disc holding the spring until the required tension is obtained, the nut being then again screwed home. The small pulley for guiding the cord is arranged on a swivel joint allowing the pulley to take any convenient position. The indicator is provided with every convenience for examining and cleaning, inserting the cord, &c.

Fig. 461 shows an exterior view of the *Thompson Indicator*, made by Messrs. Schäffer and Budenberg, and designed to overcome some objections attending the use of Richards's, by reducing the inertia of the parallel motion, so as to lessen the oscillations of the pencil, and render the instrument applicable at higher speeds.

In the novel parallel motion of the Thompson indicator, the lever carrying the pencil is very lightly made, so as to bend slightly and give the pencil a gentle elastic pressure against the paper; this arrangement does not

re-act disadvantageously upon the parallel motion as does that in the Richards indicator.

In Fig. 461 the indicator piston is connected to the main horizontal rod of the parallel motion by a connecting rod, passing inside the piston rod, which is made hollow so as to allow of this. The attachment to the piston is by means of a small double ball joint. This gives a joint which is quite free without having any play and allows of a means of adjustment by taking up any play resulting from wear on the joint. The parallel motion is carefully designed to ensure that the pencil point describes a straight line and that the motion of the pencil point is precisely proportional to the displacement of the indicator piston throughout the stroke. To suit the higher speeds for which the indicator is intended, the passage of the cock and connection is made $\frac{1}{2}$ inch, against $\frac{3}{8}$ inch in that of the Richards indicator. The piston motion is multiplied in the proportion of 1 to 4, as is also that of the Richards as made by Messrs. Schäffer and Budenberg. The stroke of the piston is only $\frac{3}{4}$ inch as against $\frac{7}{8}$ inch, the maximum height of the diagram being consequently 3 inches, against $3\frac{3}{8}$ inches, in the Richards. In all other respects the Thompson and Richards indicators are similar. The former is also made in a small size, which is intended more especially for taking diagrams at high speeds. In it the parallel motion is made very light, so that the oscillations of the pencil at the highest speeds are considerably reduced; a stronger spring than in the large instrument being invariably used. This instrument complete with fittings weighs only 5 lbs., as against 11 lbs. in the case of the large Thompson, and a still greater weight in the ordinary Richards indicator. Its greater portability gives it an additional advantage over the other instruments. The large Thompson indicator has been successfully employed at a speed of 400 revolutions per minute, whilst the small

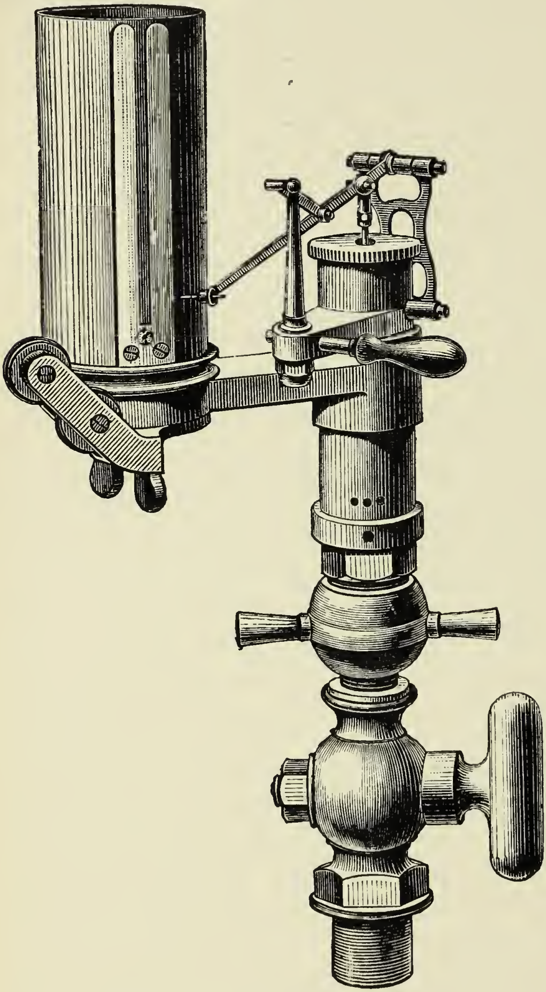


Fig. 461.—The Thompson Indicator.

Thompson may be used up to 600 revolutions per minute if a sufficiently strong spring is inserted.

If desired the apparatus can be supplied with a rising motion of the drum operated by hand for taking any number of diagrams successively on the same paper.

Messrs. Schäffer and Budenberg also make a *Double Indicator* which is a novelty in construction. In the ordinary indicator, the upper or steam-pressure curve drawn on the diagram does not in reality pertain to the back-pressure curve drawn beneath it, but belongs rather to that back-pressure curve which would result if the other side of the piston were indicated simultaneously; and the calculation from an ordinary diagram of the work done by the engine during a stroke is based upon the assumption that the action is identical during two successive strokes on both sides of the piston.

The object of the double indicator is to be enabled to place both sides of the piston in communication with the indicator at the same time, if desired, and in such a way as to record on the diagram, the actual resultant effective pressure on the piston throughout the stroke. This instrument consists practically of a combination of two indicators acting upon the pencil simultaneously, and causing the latter to record directly the resultant-pressure upon the engine piston. The double indicator has two pistons fixed upon the same spindle and when both indicator cocks are open, the pistons are subject respectively to the pressures on both sides of the engine piston, the pressure being, of course, in opposite directions in the case of non-condensing engines, and in the same direction in condensing engines. There is only one spring, and this is employed in compression upwards or downwards, according to the direction of the resulting pressure on the engine piston, the arrangement of the spring being such that it can only be used in compression. The diagram traced by this indicator is therefore situated partly above and partly beneath the atmospheric line, and the distance of the diagram from the atmospheric line at every point represents the actual resultant-pressure on the piston. The areas of the diagram above and below the atmospheric line show respectively the work of the steam on each side of the piston, and the area of the whole diagram represents the actual work performed during one revolution. If only one indicator cock be opened at a time, separate diagrams from each cylinder end may be obtained, and by taking these on the same paper as the combined diagram, a complete record is obtained which shows all the details of the separate diagrams, and facilitates the calculation of the whole diagram.

A peculiarity of the double indicator is that its indications are independent of the barometric pressure, the piston rod being equilibrated for this pressure, whilst in all ordinary indicators the atmospheric pressure acts upon the upper side of the piston.

The instrument has not become very popular owing to the diagrams obtained from it differing to such extent from those of the ordinary indicator as to puzzle the occasional user.

PRESSURE AND VACUUM GAUGES.

The first form of gauge used to determine steam-pressure was the mercury column, and it is still used as the standard of comparison when graduating existing gauges. The indications of the mercury column are most accurate and reliable in careful hands, but it is inconvenient for general use, and impossible in cases where there is oscillation, as on locomotives. Fig. 462—the *Bourdon*—

shows the type of gauge now in general use, which is the invention of M. Bourdon, a Frenchman.* It is stated that the idea occurred to him while repairing the copper pipe of a still which had become flattened. In trying to restore it to its normal shape he forced water into it under high pressure, and observed that during the process the flattened tube had a tendency to uncoil itself, and this was the more apparent as the pressure of the fluid used was increased. This principle he afterwards applied in the Bourdon pressure-gauge by using in it a flattened tube of hard elastic brass bent upon itself, closed at one end, and open to receive the fluid-pressure acting along the interior at the other. As the pressure fluid enters the tube it unbends, and the extent of unbending depends on the amount of pressure applied. A standard mercury column was used in order to ascertain the pressure equivalent to different amounts of unbending, and an indicating pointer attached showing the extent of unbending or the corresponding pressure, and the gauge as thus made is convenient for carrying and for general use. When carefully made its indications are accurate and reliable.

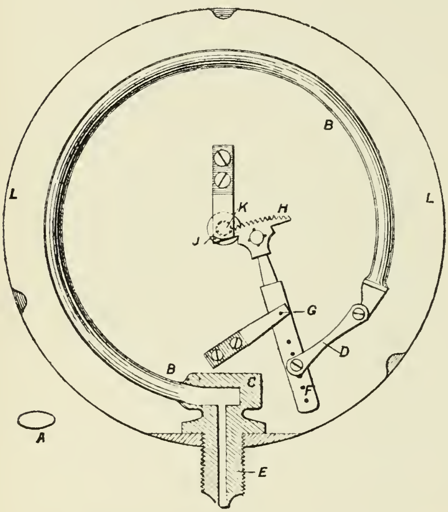


Fig. 462.—The Bourdon Pressure-Gauge.

In Fig. 462 an ordinary form of pressure-gauge is shown partly in section. The brass pressure tube, B, shown in transverse section at A, is securely soldered to the piece, C, terminating the screw, E, and is closed at the other end. The steam or other fluid under pressure is admitted by the small opening in E, and fills the tube, B. As a result, the tube tends to straighten itself, and a link, D, pulls upon a lever, F, which moves on the fulcrum, G, and by means of a toothed rack, H, rotates a small pinion, J, and with it the spindle, K. The spindle, K, carries the pointer, which moves round the dial, and indicates by its position the pressure of the steam or other fluid. It will be observed that a very small movement of the tube, in the effort to unbend, is increased to a large movement at the end of the pointer, and for that reason it is highly important that all slack or back-lash should be avoided as much as possible. It is equally necessary that friction be reduced to a minimum, or the pointer will not indicate the same during the return motion, *i.e.*, during a reduction of pressure. In the ordinary form of these gauges the brass case, L, is used as a framework upon which to attach the various parts, and when well made is quite satisfactory. Where, however, the fastenings are in the least degree insecure, such gauges are likely to give inaccurate readings. If the screw, E, be the least slack in the case, it allows movement of the tube, B, by vibration, or by accidental push or touch, and consequently may indicate pressure when none exists, or on the other hand may require a considerable pressure before it indicates anything at all. Any shifting of the brackets carrying the fulcrum, G, or the spindle, K, may also seriously affect the pointer indication. In the gauges manufactured by Messrs. Schäffer and Budenberg, of Manchester, no part of the mechanism is

* The Germans say that it is the invention of a German, Schinz, and in that country the tubes are known by his name.

attached to the case, but is all carried on one piece of metal, cast solid with the screw, to which the Bourdon tube is attached. This method avoids possibility of displacement due to defective fastenings, or inaccurate readings, if the screw should shake in its case.

Figs. 463, 464, and 465 show sectional views of such gauges, Fig. 463 being

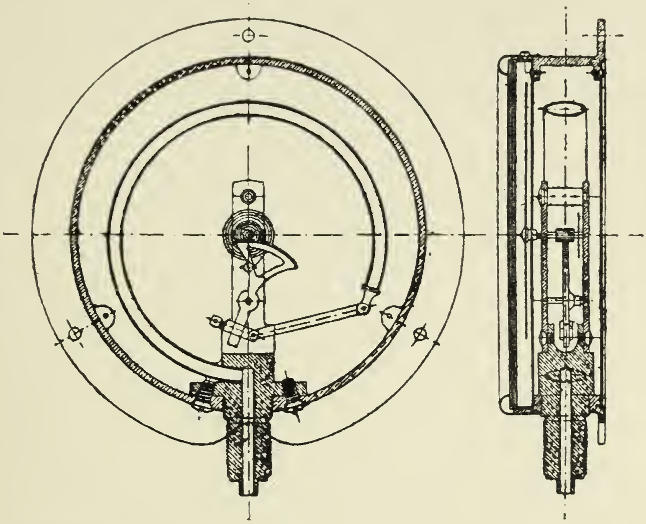


Fig. 463.—Schäffer and Budenberg Concentric Bourdon Pressure or Vacuum-Gauge.

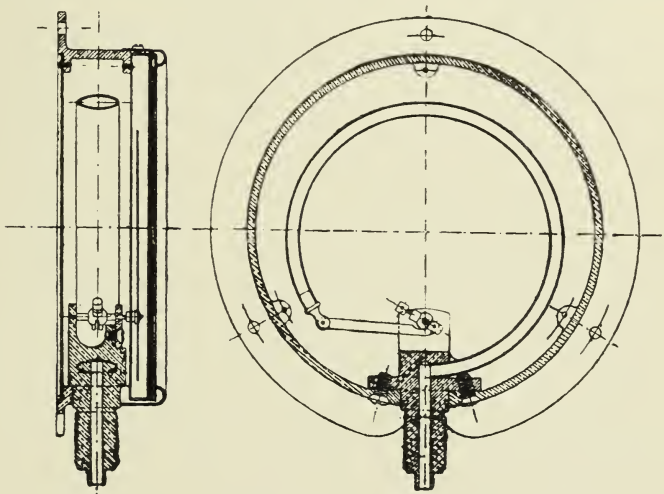


Fig. 464.—Schäffer and Budenberg Eccentric Bourdon Pressure or Vacuum-Gauge.

a concentric, and Fig. 464 an eccentric, Bourdon pressure, or vacuum-gauge, while Fig. 465 is a steel tube gauge specially constructed for indicating high steam, gas, or hydraulic pressure.

In Fig. 463 the pointer-spindle is set in motion by means of a pinion and toothed quadrant. In Fig. 464 no toothed quadrant is used, the end of the

Bourdon tube being attached direct to a lever on the pointer-spindle. In Fig. 465 the toothed quadrant is retained, but the Bourdon tube is constructed of steel instead of hard brass. These gauges were originally only intended for hydraulic purposes, but the principle has been so far modified as to allow of its being applied to gauges for all ordinary steam pressures, and they register the lower pressures with as great accuracy as the higher ones. When intended to indicate hydraulic pressure a tube nearly circular in section is adopted; in the steel-tube gauge suitable for steam pressures the tube is flattened considerably so as to be more flexible.

Ordinary steam-pressure gauges with brass tubes are unable to indicate constantly

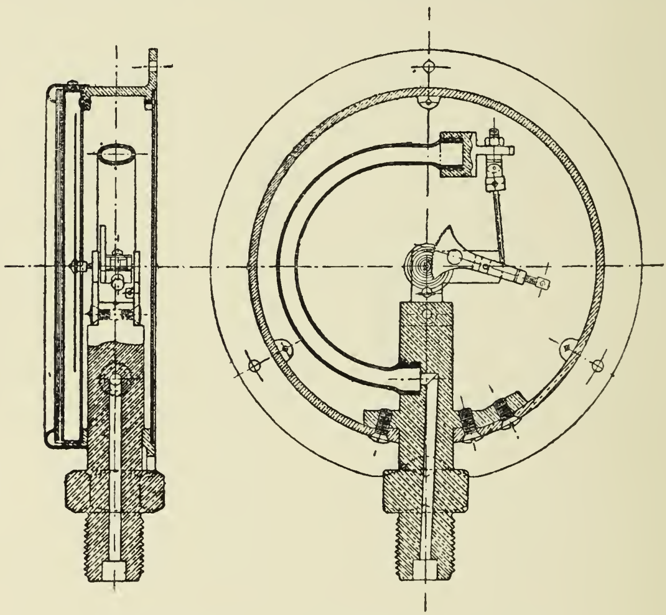


Fig. 465.—Schäffer and Budenberg Steel Tube Gauge.

such high pressures as 300 lbs. per square inch, and still more so pressures very much higher which are needed for high pressure tubing, hydraulic presses, &c. In Fig. 465 the type of gauge is designed to overcome these difficulties, and may be made to indicate different ranges of pressures varying from 120 lbs. to 30 tons on the square inch. The springs are manufactured from English-made steel rods of the highest quality attainable, the rods being cut to the proper length of the springs required; they are bored out, and turned off outside, except the ends, to which a suitable thread is screwed. The straight tubes are then heated to a certain temperature, and bent, the bending operation being followed by a flattening and shaping process. After tempering, one end is screwed into the stem or principal part of the gauge, through which the pressure is carried on from the generator, and upon the other end is screwed a solid piece of metal or cap, to which the rod is fixed, transmitting the movements of the steel spring by suitable gearing to the pointer and dial of the gauge.

Although the steel tube springs stand perfectly well without corrosion, if constantly under water, they cannot resist it when intermittently employed, as this allows air to be admitted, following the water, and results in signs of corrosion. This difficulty has been overcome by tinning, for which process

Messrs. Schäffer and Budenberg have obtained a patent. By it both the interior and exterior of the steel tubes are plated with tin. They thus effectually resist corrosion, and may be used as test gauges with any required intervals of time between periods of employment. They are exceedingly durable, retaining perfect elasticity, and have the great advantage that all soldering is avoided, which is requisite in the Bourdon, and other usual constructions in which the spring consists of a brass tube.

These high-pressure gauges, in addition to their application to hydraulic presses, are exceedingly useful in ascertaining the breaking strain of iron and steel bars, chain cables, water pressure in accumulators, air compressors, as also in connection with the manufacture of torpedoes, for which purposes they are used at the Arsenal at Woolwich, Sir William Armstrong & Co.'s, and Sir Joseph Whitworth & Co.'s, and other works.

Duplex gauges have two complete and perfectly distinct gauge works and tubes communicating with the same inlet, and they therefore check their own indications. They are made in two forms by Messrs. Schäffer and Budenberg, in one of which, adapted for a steel tube test gauge, the two pointers, when at zero near the top of the gauge, are some distance apart, and move in opposite directions, when operated by pressure from the generator. The dial face is divided into two corresponding even divisions, each being contained in rather less than a half circle on the dial, and numbered up to the range of pressure the gauge is made for. The two pointers should always indicate the same pressure. In the other form the pointers overlap each other, so as to indicate on the same scale, the arbor of one of the pointers being made hollow, while the other is passed through the former.

The dial plate of each ordinary gauge made by Messrs. Schäffer and Budenberg, is graduated separately, and by actual comparison with a standard mercury column. When made, the gauge is left with a blank white dial, and in this state is screwed to a connection leading to an open mercury column and a force pump. Motion is given to the pump, which forces up the mercury on a measured scale, and on which is marked the number of pounds per square inch, corresponding to the height of the column. The column ascends the whole height of the building, and the position of the mercury is read by assistants placed at various levels. Marks are made upon the dial of the gauge, corresponding to every increase of 1 lb. pressure, and the dial is afterwards finished with the graduations as thus determined experimentally.

For the purpose of comparing different gauges a hydraulic cylinder is used, the piston of which is actuated by a screw and hand-wheel. The gauges are attached to couplings prepared for them, and their indications may be compared with a standard tested gauge by merely turning the hand-wheel, and forcing the fluid used (preferably oil) into each.

The great height which would be required for the purpose, renders it impracticable to test the steel tube gauges by comparison with a mercury column; they are, therefore, tested by pumping up the pressure on the gauge, and against a loaded ram, having a definite known area and load. Special arrangements are made to reduce the friction to a minimum, and allowance is made in the graduations for the friction, the amount of which is determined by the aid of the mercurial column.

Bourdon vacuum gauges are constructed on the same principles as pressure-gauges, but are distinctive in consequence of their more delicate and sensitive character, designed to suit the slight range of low pressures to be indicated. In their construction the tube springs are made lighter and much flatter in section than those used in the pressure-gauges. It is of the utmost importance to reduce friction to a minimum, and for that purpose, multiplying gear is dispensed with;

the link from the end of the tube spring being attached direct to the lever on the pointer spindle similar to Fig. 464. To avoid oscillations resulting from slight vibration, the Bourdon tube must be proportioned so that small changes of pressure produce ample power to move the indicating gear and pointer. In a properly made and proportioned instrument the pointer should always come back to zero on being released from the pressure deflecting it, however slowly it is moved, and if when pressure is on the gauge, it be deflected and then allowed to return, it should invariably settle at the true pressure. The most trying test is when the deflection of the pointer is slow, followed by a slow return. To test vacuum gauges, they are placed on a stand alongside a tube immersed in mercury and an air-pump. A scale of inches is attached to the mercury tube and the air-pump is connected to a coupling for carrying the gauge and also to the top of the mercury tube. On starting the air-pump the air is removed from the gauge and above the mercury and the scale of inches above the mercury level shows the vacuum.

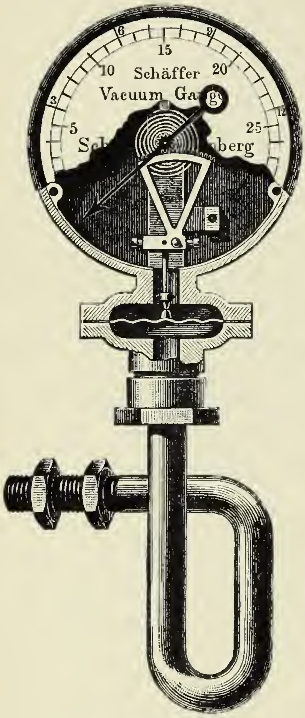


Fig. 466.—Schäffer Diaphragm Gauge.

Besides the Bourdon, Messrs. Schäffer & Budenberg make a diaphragm gauge known as the *Schäffer*, and shown at Fig. 466. This gauge was patented by Schäffer as early as 1859, *i.e.*, prior to the invention of the Bourdon gauge, and is available for pressures up to 300 lbs. per square inch. Its most noticeable feature is the corrugated steel diaphragm shown in the drawing, which serves to receive the pressure of steam or a fluid. In pressure-gauges the steel diaphragm is backed up by a spring thrusting against the steam pressure, and the movement of the diaphragm is communicated to the pointer by the lever-toothed quadrant acting on a pinion attached to the pointer spindle. The helical spring surrounding the spindle, is intended to take up all backlash, by keeping the pinion teeth always bearing upon one side against the quadrant teeth. To protect the steel diaphragm from the corrosive action of the steam it is covered by a thin pliable sheet of silver foil shaped to fit the corrugations. This sheet is so thin as to allow free movement of the diaphragm whilst effectively protecting it from corrosion.

LIGHTNING DESCENDING SHAFTS.

A danger to which collieries are liable is the descent of lightning to the underground workings during a thunderstorm. Well authenticated instances have been placed on record which leave no doubt that lightning has been observed to traverse the underground workings; but in all instances without serious damage having resulted from it. Some mines are so placed that they seem to invite the descent of lightning into the workings. The colliery may be situated on elevated ground, the underground workings be dry, and the ropes, rapper wires, iron guides, steam or water pipes afford the means of conducting the electric spark to the flat sheets at the landing stage, and these again being

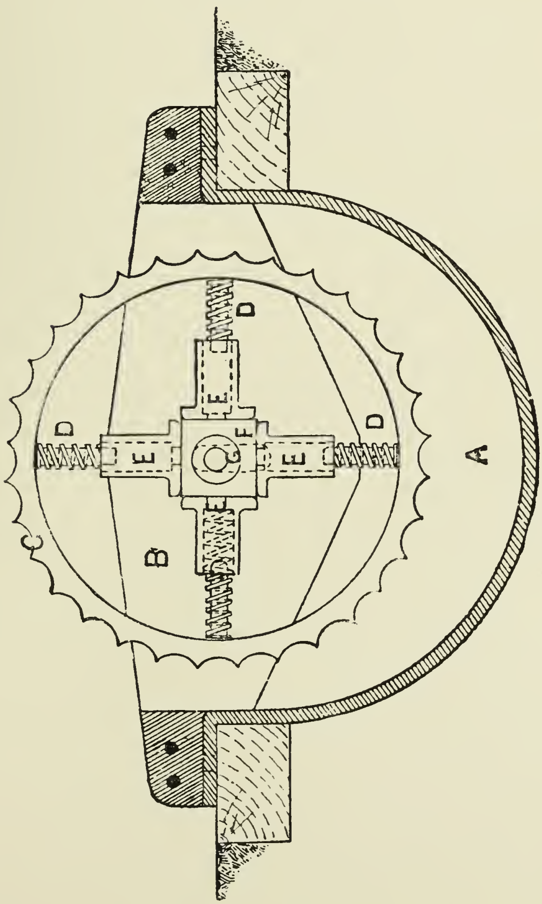


Fig. 467.—Section.

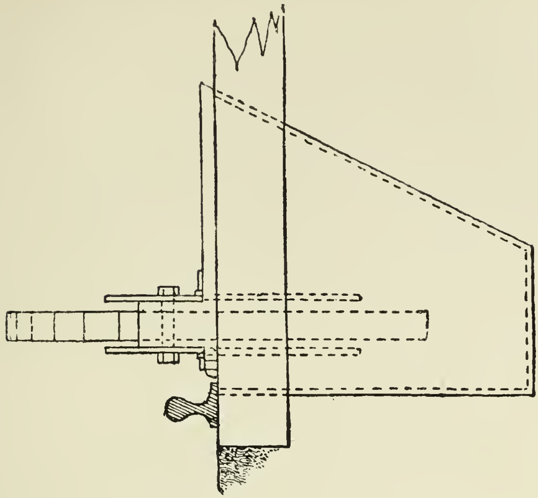


Fig. 468.—End View.

Dunford and Emens' Patent Automatic Greasing Apparatus.

connected with the rails leave an unbroken course for the lightning, especially if the rails are "fished" at the joints. Whether it is possible for the lightning to fire an explosive mixture of air and gas in the workings is not considered certain although surely highly probable. The fact that an explosion occurred at Risca some years ago during a thunderstorm has given rise to some discussion on the subject.

To prevent the possibility of lightning discharges entering pits, the mouths of the shafts should be efficiently protected, and this may be done by fixing lightning conductors to all lofty chimneys and buildings in the neighbourhood, and these conductors should terminate with a good earth-plate sunk in the ground, or preferably in the bed of a stream or a reservoir of water. The lightning conductors should, of course, be placed sufficiently above the chimneys or buildings. If these are at some distance from the shaft it may be advisable to fix a conductor at the headstock of the pit, taking care to carry it as high as possible and to have the end carried to an earth-plate.

AUTOMATIC GREASING APPARATUS.

Many forms of tub-greasers have been designed with a view to save labour in applying the necessary lubricant to colliery tubs, and to avoid wasting the lubricant in the act of its application. Some of them do their work most inefficiently, and are liable to get out of order and damage the rolling stock they are intended to lubricate. There can be no doubt, however, that a well-designed automatic tub-greaser is calculated to effect a considerable saving at large collieries. The following description of Dunford and Emens' Patent Automatic Greasing Apparatus (Figs. 467 and 468) is given by Messrs. Dunford Brothers, of Newcastle-on-Tyne:—

"A—Semicircular Trough, fixed to the sleepers, to contain the grease, with bevelled side to incline the grease towards the wheel. B—Two Side Plates to carry the wheel, with slots to allow of the wheel being easily raised or lowered. C—Corrugated Wheel, with 4 short arms. The wheel revolving in the grease, raises in its corrugations a sufficient quantity of grease to efficiently lubricate the axles. D—Four Best Tempered Steel Spiral Springs, which hold the wheel in position, and allow of its eccentric action. E—Four Cases, to hold the springs, the short arms of the wheel being inside the springs and below the level of the top of the cases. F—Square Boss, on which the spring cases slide, allowing the wheel to assume an eccentric position when struck at an angle. G—Centre Piece, on which the square boss revolves, allowing the wheel to have a rotary motion, a bolt and nut passing through the centre piece holds it firm to the side plates.

"The apparatus is intended to be placed in a convenient situation, one on each side between the rails of the tramway, so that each tub of a train passing over it in either direction will receive on the journals of each of its axles an adequate quantity of the grease lubricant, any *excess* being *returned* to the *reservoir*.

"It consists of a semi-circular trough containing the lubricant, the upper end of which is level with the ground, and covered in to keep out dirt or coal dust, except the space through which a wheel works, the rim of which is in breadth suitable for the axle journal, and has formed across it, all round, concave recesses which contain the lubricant. The rim of the wheel, instead of being rigidly connected to the boss or centre by arms, has an elastic connection by means of four spiral springs enclosed in tubular cases interposed between the rim and the boss (which has four flat faces), upon which the feet of the tubular cases enclosing the springs slide freely, the result being that when the axle of a running tub comes into contact with one of the concave recesses in the rim, the journal receives a charge of lubricant, and, besides revolving the rim, pushes it in the direction in which it is running, the springs yielding, and the feet of

the enclosing cases sliding on the flat faces of the boss, the rim being pushed temporarily into a position eccentric to the centre of its axle till the tub axle has passed over, when it returns to its normal position, to be acted upon in the same manner by the next following axle, which receives a fresh charge of lubricant. Thus the rim will suit itself to tubs having wheels of different diameters to the extent of several inches.

"The greasing wheel on one side of the line is entirely unconnected with the wheel on the other side; each acts freely to administer a charge of grease to the journal on its own side of the line of tubs.

"Where the tub wheels revolve on the axles this greaser is useless, but is very efficient for tubs to which the wheels are fixed to the axle and the whole revolve."

The Hardy Patent Pick Company, Limited, Sheffield, supply a Self-Lubricating Pedestal for Colliery Tubs which is designed also to protect the axles of the tubs from dust. This is of much importance, especially in dusty mines, where ordinary bearings get full of coal dust which renders useless the newly applied lubricant. The construction of the bearing is very simple. The top portion bearing the load is similar to the old form of pedestal, but underneath a steel dish is fitted, which keeps the axle free from dirt and at the same time prevents it from leaving its bearing. The steel dish is stamped out of one sheet of metal, and is shaped to hold a quantity of felt or wool, which bears against the axle on the under side, and being soaked with the lubricant, keeps the journal well oiled. When first charged about 5 oz. of oil is required in the operation, but when necessary to replenish, a charge of 2 oz. is sufficient. It is said that the tubs will work two or three months without further attention, after once oiling, and the journals remain clean and well-oiled throughout that time. A tub with outside bearings may have the lubricant applied to the journals at any time as the tub rests on its wheels, but with inside bearings it is necessary to turn the tub by means of a lifter and then the oil may be poured through a hole which leads into a large hollow space in the top of the bearing plate. On returning the tub to its usual position on its wheels the oil runs down into the wool or felt.

CHAPTER XV.

MISCELLANEOUS QUESTIONS AND ANSWERS.

Denudation—Meeting of Cages in a Shaft with Flat Winding Ropes—Outstroke and Wayleave—Pressure of Water Against a Barrier—Applying the Result Obtained from Boring—Discharge of Water from a Bore-hole—Pressure per Square Inch Produced by an Air-Compressing Engine—Description of Anthracite, Semi-Bituminous, Bituminous, Cannel, and Lignite Coals—Dynamometer—Elements of Rocks—Relative Hardness of "Rock Masses"—Beds and Veins of Minerals—Difference of Vein, True Fissure Vein, and Lode.

Question 152.—What is meant by denudation?

By denudation is meant the wearing and carrying away of the solid materials of the land by the agency of water. Rivers so carry away portions of the land through which they flow; the tidal currents of the ocean lay bare the rocky materials of its shores by wearing away their superficial deposits and by sweeping away the solid masses. The effect of the tidal current of the German Ocean is to sweep away large masses along the eastern coast of England and to make a gradual inroad in the land annually. The soil and other matters transported by the action of rivers from inland situations are brought to the sea and borne by the ocean currents to a much greater distance from their original site. It has been computed that the Hoang-Ho, one of the largest and most rapid rivers in China, brought down in a single hour two million feet of earth. The Ordnance survey now (1890) proceeding in Yorkshire proves an erosion of the coast there. The portion of the coast line which has been surveyed as yet, viz., that between Great Colden and Dimlington, has been almost uniformly encroached upon, since 1852, by the sea for about 215 feet, or at the rate of 5 feet 10 inches per annum.

Question 153.—At what point in the shaft would the cages "meet" if flat ropes, $\frac{3}{4}$ of an inch thick, are used for winding; the drums are 10 feet in diameter at the lift, and the depth of the pit 612 feet?

In winding with a flat-rope drum each coil of rope is wrapped upon the preceding coil every revolution that is made, and as the cage is drawn up from the pit bottom the diameter of the drum constantly increases and attains its maximum diameter when the cage reaches the surface. Again, as the cage is being lowered, the effective diameter of the drum constantly decreases and reaches its minimum when the cage has arrived at the shaft bottom. The increase in the diameter of the drum, the first revolution will be equal to the rope's thickness (because the rope in bending on the drum is lengthened on the convex side and shortened on the concave side equally, the centre of the rope retaining its former length), and for each successive revolution after the first the increase of the drum's effective diameter will amount to twice the thickness of the rope.

Let d = depth of pit in inches.
,, t = thickness of rope in inches.
,, x = diameter of drum in inches.
,, n = number of revolutions.

Then the diameter of the drum at the first and succeeding revolutions will be—

$$x + t = \text{1st diameter.}$$
$$x + 3t = \text{2nd do.}$$
$$x + 5t = \text{3rd do.}$$

and so on, and at the nth revolution the diameter will be represented by $x + t(2n - 1)$. The circumference will therefore be—

$$\pi(x + t) = \text{1st revolution.}$$
$$\pi(x + 3t) = \text{2nd} \quad ,,$$
$$\pi(x + 5t) = \text{3rd} \quad ,,$$
$$\text{And } \pi\{x + t(2n - 1)\} = n\text{th} \quad ,,$$

Since this series of terms are in arithmetical progression, their sum may be obtained in the usual way, and it will be, $n\pi(x + nt)$ which is equal to the length of rope wound on the drum, and therefore the depth of the pit. Therefore, $d = n\pi(x + nt)$. Or by denoting the depth of the pit in yards by D, then

$$D = n(x + nt) \times \cdot087266,$$

from which the following formulæ are deduced :—

$$D = n(x + nt) \times \cdot0872 \qquad (1)$$

$$x = \frac{11\cdot45915\,D}{n} - nt \qquad (2)$$

$$t = \frac{11\cdot45915\,D}{n^2} - \frac{x}{n} \qquad (3)$$

$$n = \frac{\sqrt{11\cdot45915\,Dt + \left(\frac{x}{2}\right)^2} - \frac{x}{2}}{t} \qquad (4)$$

Now to consider the position of the meeting of cages.

When the engine begins to wind, the drums, being fixed on the same shaft of the engine, move simultaneously, thereby causing the one cage to be raised as the other is lowered. But the descending cage will pass through a greater space than the ascending cage in the same time; the excess in space travelled by the former over the latter gradually diminishing until the engine has made half the number of the total revolutions for one wind.

The diameters of the two drums will then be equal and the cages will be alongside each other or at meetings in the pit. The position of meetings then must be at a point below the middle of the shaft, and the distance of this point below mid-shaft will depend on the thickness of the rope and the number of revolutions made. It follows that after passing each other in the shaft, the ascending cage will move through a greater space than the descending one in the same time, as the diameter of the drum to which the ascending cage is attached becomes larger and the drum of the descending cage becomes smaller in diameter than the mean diameter at meetings.

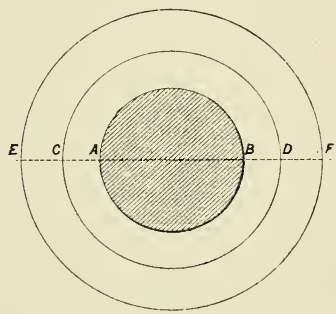


Fig. 469.—Flat Rope Drum, showing Changes in its Diameter.

In Fig. 469, the diameter of the drum is represented by A B; C D representing

its diameter at meetings and E F, its diameter when the cage has arrived at the top of the pit. It will be seen that the area of the annular spaces C A B D, and E C D F are equivalent respectively to the edge area of the rope wound on the drum between the bottom of pit and meetings, and that wound off the drum between the top of pit and meetings, and the difference between these areas will obviously give the area of that portion of the rope corresponding to the distance travelled by the descending over the ascending cage, and half this distance will be the point of meeting below mid-shaft. Adopting the same notation as before for the different parts, we have $E\,C = C\,A = B\,D = D\,F = \frac{nt}{2}$. $E\,F = x + 2nt$ and $C\,D = x + nt$.

$$\left.\begin{array}{r}\text{Therefore the area}\\ \text{of E C D F}\end{array}\right\} = \cdot 7854 \left\{(x + 2nt)^2 - (x + nt)^2\right\}$$

$$= \cdot 7854\,(2\,xnt + 3\,n^2\,t^2) \qquad (a)$$

$$\text{and the area of C A B D} = \cdot 7854 \left\{(x + nt)^2 - x^2\right.$$

$$= \cdot 7854\,(2\,xnt + n^2\,t^2) \qquad (b)$$

Subtracting b from a we get $\cdot 7854\ (2\ n^2\ t^2)$ which is the difference of areas in square inches, and dividing by t we have $\cdot 7854\ (2\ n^2 t)$, the difference of the lengths of rope. Hence, dividing by 2 we get $\cdot 7854\ n^2 t$, the distance of meetings below mid-shaft in inches. If this distance be required in yards (say m) we have

$$m = \frac{\cdot 7854\ n^2 t}{36} = \cdot 021816\ n^2 t$$

Therefore, representing the position of meetings from the top and bottom of the pit by p, and $p_{\prime}$, respectively we have

$$p = \frac{D}{2} + \cdot 021816\ n^2 t. \qquad (5)$$

$$p_{\prime} = \frac{D}{2} - \cdot 021816\ n^2 t. \qquad (6)$$

Proceeding now to the question given, first find the number of revolutions of the engine, and this will be done by the aid of formula (4), thus

$$n = \frac{\sqrt{11 \cdot 45915 \times 204 \times \cdot 75 + (\frac{120}{2})^2} - \frac{120}{2}}{\cdot 75} = 17 \cdot 55336.$$

Now apply the data to formula (5), thus $p = \frac{204}{2} + (\cdot 021816 \times 17 \cdot 55336^2 \times \cdot 75) = 107 \cdot 0416$ yards or $107 \cdot 0416 \times 3 = 321 \cdot 1248$ feet as the distance of point of meetings from the surface $\therefore\ 612 - 321 \cdot 1248 = 290 \cdot 8752$ feet as the distance of point of meetings from the bottom of the shaft, or the latter may, if preferred, be found from formula (6).

Question 154.—A winding-engine draws coals from a pit 150 fathoms deep, drum 14 feet in diameter at the lift, flat ropes $\frac{3}{4}$-inch in thickness, find the meeting of cages.

In replying to this question, adopt a different method of working from the last, so that those familiar with algebraical expressions and who do not care to carry a formula in their memories may proceed in this way. The reasoning is similar to that of the previous method shown and the result obtained the same as would be got by that method. It is also applicable to solving the "meeting" place when conical drums are used with round ropes.

Let $x =$ the number of revolutions of the drum in running the cages in the pit.

And $y =$ diameter of drum in feet at the last revolution.

Then $y = \cdot 125\,x + 14$, because twice the thickness of the rope in feet is $\cdot 125$.

And $x = 8y - 112$.

$\frac{y + 14}{2} \times 3\cdot141593 =$ mean circumference of drum $= 1\cdot570796y + 21\cdot99115$ which divided into the depth of the pit (in feet) gives the number of revolutions of the drum.

Therefore $x = \frac{900}{1\cdot570796y + 21\cdot99115}$

substituting for x we have

$$8y - 112 = \frac{900}{1\cdot570796y + 21\cdot99115}$$
$$12\cdot566368y^2 - 2{,}463 = 900$$
$$12\cdot566368y^2 = 3{,}363$$
$$y^2 = 267\cdot62$$
$$y = 16\cdot359$$
$$x = 8(16\cdot359) - 112 = 18\cdot872$$

Number of revolutions of drum $= 18\cdot872$.

Diameter of drum in feet at last revolution $= 16\cdot359$.

$\frac{16\cdot359 + 14}{2} = 15\cdot1795$, mean diameter of drum.

$15\cdot1795 \times 3\cdot14159 \times 18\cdot872 = 900$.

Depth from surface to meeting of cages $\Big\} = \frac{16\cdot359 + 15\cdot1795}{2} \times 3\cdot14159 \times \frac{18\cdot872}{2}$.

$= 467\cdot464$ feet.

$=$ 77 fathoms, 5 feet, 5·568 inches.

say 77 fathoms, 5 feet, 6 inches.

Distance of meetings from the bottom of pit $\Big\} = \frac{15\cdot1795 + 14}{2} \times 3\cdot14159 \times \frac{18\cdot872}{2}$

$= 432\cdot5$ feet.

$=$ 72 fathoms, 0 feet, 6 inches.

And the accuracy of the result is shown by adding together

	fathoms.	ft.	inches.
	77	5	6
And	72	0	6
Depth of pit	150	0	0

If the formula already given be applied to the working of this question, precisely the same result will be obtained.

Question 155.—A shaft 34 fathoms deep is worked by a drum 3 feet in diameter. It is required to find the diameter of another drum which must be keyed on the same axis to wind from another shaft 21 fathoms deep, flat ropes, 1 inch thick, being used to coil one lap upon the other?

In considering this question it is obvious that there must first be ascertained the number of revolutions of the 3-foot diameter drum in drawing the cage up the 34-fathom shaft, and then as the same number of revolutions must draw the cage up the 21-fathom shaft, proceed to find the diameter of drum

for the shallower shaft, knowing the depth, number of revolutions, and thickness of rope.

Adopting formula (4) given in answer 153, and using the same values for the symbols there given, the number of revolutions in the 34-fathom shaft $n =$

$$\frac{\sqrt{11{\cdot}45915 \times 68 \times 1 + \left(\frac{36}{2}\right)^2} - \frac{36}{2}}{1} = 15{\cdot}21$$ revolutions. Now use formula (2) given in Answer 153, to find the diameter of drum for the 21-fathom shaft, thus

$$x = \frac{11{\cdot}45915 \times 42}{15{\cdot}21} - 15{\cdot}21 \times 1 = 16{\cdot}432 \text{ inches}$$

as the diameter of drum required for the 21-fathom shaft.

Question 156.—A shaft 100 fathoms deep is worked by a drum 12 feet in diameter. What must the diameter of another drum be which is keyed to the same axis to wind from another shaft 120 fathoms deep, flat ropes being used, $\frac{3}{4}$ of an inch thick, to coil one lap upon the other?

This may be worked in a similar manner to the previous question, but proceed to work it algebraically in order to show another method of obtaining the same result. Dealing with the shaft whose depth and size of drum are known, the revolutions may be found thus:—

Let $x =$ the number of revolutions of the drum whilst the cage travels from the bottom of pit to the top,

and $y =$ diameter of drum in feet at the last revolution.

Then $y = {\cdot}125x + 12$, because twice the thickness of rope is ·125 foot, and $\therefore x = 8y - 96$.

$\frac{y + 12}{2} \times 3{\cdot}141593 =$ mean circumference of drum $= 1{\cdot}570796y + 18{\cdot}84956$, which, divided into the depth of the pit (in feet), gives the number of revolutions of the drum.

$$\text{Therefore } x = \frac{600}{1{\cdot}570796y + 18{\cdot}84956}$$

substituting for x we have

$$8y - 96 = \frac{600}{1{\cdot}570796y + 18{\cdot}84956}$$

$$12{\cdot}566368y^2 - 1{,}809{\cdot}55776 = 600$$

$$12{\cdot}566368y^2 = 2{,}409{\cdot}55776$$

$$y^2 = 191{\cdot}75$$

$$y = 13{\cdot}85$$

$x = 8\,(13{\cdot}85) - 96 = 14{\cdot}8$, which is the number of revolutions.

The mean diameter of the drum for the 120-fathom shaft will be found by dividing the depth (in feet) by the number of revolutions multiplied by 3·14159, thus $\frac{120 \times 6}{14{\cdot}8 \times 3{\cdot}14159} = 15{\cdot}485$.

To find the diameter at lift.

Let $x =$ the diameter of the drum at lift.

Then half the number of revolutions will increase the drum to its mean diameter $\therefore x + ({\cdot}125 \times 7{\cdot}4) = 15{\cdot}485$, and $x = 14{\cdot}56$, which is the diameter the drum must be for the 120-fathom shaft in feet.

The accuracy of this working may be checked by the formula already given, when precisely the same result will be arrived at.

Question 157.—Suppose an engine-house to be 15 yards from a pit, the ground (from the engine-house to the pit) rising 2 inches in 6; the height of drum from the surface is 3 feet, and the perpendicular height of framing to top of pulley wheel 25 feet: what would be the gradient from the drum to the pulley wheel?

To assist the answer refer to Fig. 470.

As the ground rises 2 inches in 6 or $\frac{6}{2} = 3$, 1 in 3, in 45 feet it rises $\frac{45}{3} = 15$ feet, and as the top of the drum is 3 feet above the level of the ground $15 - 3 = 12$ feet as the ground level at the pit above the top of drum. To this add height of the pulley above the ground, viz., 25 feet, and we get 37 feet. Therefore there is a vertical height of 37 feet in 45 feet, or $\frac{45}{37} = 1$ in $1{\cdot}216$, or $\frac{37}{15} = 2{\cdot}4\dot{6}$ feet rise per yard as the gradient of the rope.

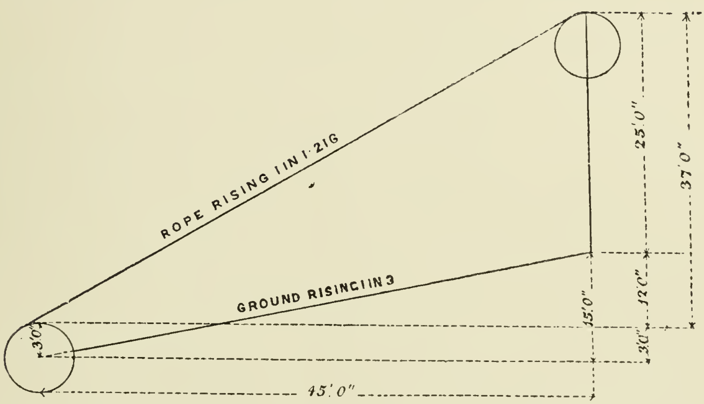


Fig. 470.—Sketch showing Inclination of Winding-rope and Ground at the Pit.

Question 158.—Explain the meaning of the words outstroke and wayleave which are frequently found in a mineral lease?

Outstroke is the privilege of breaking the barrier and working and conveying underground the coal from an adjoining royalty. Wayleave is a right on payment of a certain tonnage-rate expressed in the lease to convey coals gotten from an adjoining royalty to the shaft or elsewhere.

Question 159.—What is the pressure of water standing against a barrier 65 yards long, 4 feet $5\frac{1}{2}$ inches high, whose perpendicular height is 45 yards?

Here $45 \times 3 = 135$ feet, the height from the bottom of the seam. Then the mean vertical pressure $= 135 - 2{\cdot}23 = 132{\cdot}77$ feet, and $132{\cdot}77 \times 62{\cdot}4 = 8{,}284{\cdot}848$ lbs. pressure per square foot of section. Sectional area of barrier $= 65 \times 3 \times 4{\cdot}46 = 869{\cdot}7$ square feet. Therefore $869{\cdot}7 \times 8{,}284{\cdot}848 = 7{,}205{,}332{\cdot}3056$ lbs., or $3{,}216{\cdot}6$ tons as the mean pressure of water against the barrier.

Question 160.—A bore-hole A finds coal at 50 yards, at B another bore-hole finds the same seam at 60 yards, B being 500 yards from A in a line bearing N. 30 E. At C, a third bore-hole proves the same seam at a depth of 70 yards, C being 500 yards from B in a line S. 30 E. What is the direction of (*a*) level course, (*b*) direction of dip, (*c*) rate of dip?

The bearing of C from A must be due east (see Fig. 471), and since A is 50 yards deep and C 70 yards, a point half-way between them must be 60 yards to the coal. Therefore, a line connecting that point with B, which is also 60 yards deep, shows the level course of the seam, and this line is due north and south,

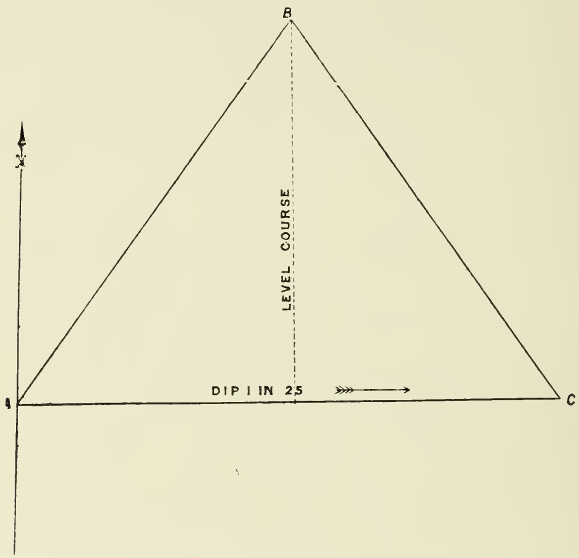


Fig. 471.—Site of Three Bore-holes.

and the dip is therefore due east, at right-angles to the north line. The point C must also be 500 yards from A, the lines connecting the bore-holes thus forming an equilateral triangle. As the difference in level of the seam between the points A and C is $70 - 50 = 20$ yards, the dip is $\frac{500}{20} = 1$ in 25.

Question 161.—What quantity of water will be discharged from a $1\frac{1}{2}$-inch bore-hole, 5 yards long, under a head of 100 feet of water?

According to Greenwell's rule we have—

$$v = 2{,}837{\cdot}5 \sqrt{\frac{P\,d}{l}}$$

and gallons per minute $= 6{\cdot}25\, v \times {\cdot}7854\, d^2$.

where $P =$ Pressure in feet.

$d =$ Diameter of bore-hole in feet.

$l =$ Length of bore-hole in feet.

$v =$ Velocity at point of issue in feet per minute.

$$v = 2{,}837{\cdot}5 \sqrt{\frac{100 \times {\cdot}125}{15}} = 2{,}590 \text{ feet per minute,}$$

and gallons per minute $= 6{\cdot}25 \times 2{,}590 \times {\cdot}7854 \times {\cdot}125^2 = 198{\cdot}66$ gallons per minute.

Hawkesley's formula is

$$G = \sqrt{\frac{(15\,D)^5 H}{L}}$$

where $G =$ Number of gallons delivered per hour.
$D =$ Diameter of pipe in inches.
$H =$ Head of water in feet.
$L =$ Length of pipe in yards.

$G = \sqrt{\frac{(15 \times 1{\cdot}5)^5 \times 100}{5}} = 10{,}739$ gallons per hour, and $\frac{10{,}739}{60} = 179$ gallons per minute, showing there is a difference in working out the formulæ given by the two authorities named.

Question 162.—How is the pressure per square inch an air-compressing engine will produce under the following circumstances, obtained?—2 steam-cylinders, each 30 inches in diameter, 7-foot stroke, pressure of steam 45 lbs. per square inch, one air-cylinder 36 inches in diameter, and one twenty inches in diameter.

If the air-compressing pistons have the same length of stroke as that of the steam-pistons, viz. 7 feet, the pressures per square inch, that will keep the steam and air pistons in a state of equilibrium, will be inversely proportional to the sum of the squares of the diameters of the cylinders. Or, expressing the same thing in another way, the product of the number of square inches on the surface of the two steam-pistons, multiplied by the pressure of steam per square inch, will equal the product of the number of square inches on the surface of the two air-pistons multiplied by the pressure of air per square inch. Let $p =$ the pressure of air per square inch. Then $p \times \{(36^2) + (20)^2\} \times {\cdot}7854 = 30^2 \times 2 \times 45 \times {\cdot}7854$. Cancelling $\cdot$7854 from both sides of the equation we have $p \times (1{,}296 + 400) = 45 \times 1{,}800$ and $p = \frac{45 \times 1{,}800}{1{,}696} = 47{\cdot}759$ lbs.

This would keep the pistons in a state of equilibrium, but for motion to take place the air pressure must be less. Allow 1 lb. per square inch for friction of each of the four pistons, which will reduce the pressure of air per square inch to 43·759 lbs. If the compressed air is conveyed along a system of pipes, the pressure at the end of such pipes will depend upon their length and diameter, more particularly the diameter, as on this will depend the velocity of the air, the friction of which will increase as the square of the velocity.

Question 163.—Describe anthracite, semi-bituminous, bituminous, cannel and lignite coals.

Anthracite coal is somewhat difficult to describe, on account of its variations in quality. Anthracite proper is shiny and bright in appearance, and is hard and brittle. It is difficult to light, but when burning develops great heat, especially when a strong draught is applied to it. It decrepitates in burning, and this property is believed to be due to the presence of water between the fibres of the coal; this water being heated is converted into steam, thus splitting up the coal. No smoke is emitted from its combustion. It does not soil the fingers on being handled, and is further distinguished by its high specific gravity and large proportion of carbon (from 90 to 95 per cent.), whilst it has a low percentage of sulphur and ash.

Anthracite is sometimes called "stone coal;" in Scotland "blind coal," and in Ireland it is known as "Kilkenny coal." The deposits in Ireland and Scot-

land are limited and poor in quality, but those of South Wales are largely developed.

The term bituminous as applied to coal is somewhat deceptive, because bitumen is soluble in alcohol, but coal is not, and does not contain any real bitumen. By bituminous coal it is understood that oxygen, hydrogen, and nitrogen enter more largely into its composition than in anthracite and give it a more flaming character in burning. The semi-bituminous coal occurs next above the anthracite in geological order, and has a larger proportion of volatile matters than anthracite, burns with more flame, and evolves smoke though not in large volumes. In colour it is dull-black. It does not cake together in burning, and is therefore called free-burning and steam-coal. The bituminous coal occurs above the semi-bituminous and contains a larger proportion of volatile matters. The bituminous coal includes several varieties of different degrees of richness in volatile matters, and it is usual to divide them into three classes,—the clear-burning, the flaming or caking, and the fuliginous, the clear-burning being the poorest and the fuliginous the richest in volatile matters. The coke made from the clear-burning is superior to that produced by any of the more bituminous varieties, but coke is made from all the bituminous coals. The flaming or caking coals are valued as household coals according to their freedom from ash.

Cannel coal is very similar in appearance to jet, but the latter is somewhat lighter than cannel and contains less foreign earthy matter. It may be recognised by its appearance, being of a dull black colour; it is opaque, compact, and brittle, breaking with a smooth conchoidal or shell-like fracture. It is very rich in gas, ignites readily, and burns with a bright flame like that of a candle. It scarcely soils the fingers when touched, and gives off very little smoke in burning. It frequently contains the teeth and scales of fishes. The cannel varieties of coal are generally considered to represent an intermediate stage of the change in chemical composition, which has resulted in the conversion of lignite into bituminous coal and are hence usually found to occupy a corresponding position in the coal strata. Varieties occur chiefly in Yorkshire, Lancashire-North Wales, and in the Lanarkshire, Mid Lothian, Fife, and Ayrshire coal, fields. Some of these varieties decrepitate and crack loudly on the fire. It is largely used for gas-making.

Lignite or brown coal is formed of a mass of vegetable matter, some varieties presenting the appearance of undecomposed wood. Its colour is from brown to pitch black, its lustre sometimes resinous, sometimes dull. It burns easily and gives a smoky flame and unpleasant odour. It has a much larger proportion of oxygen than the bituminous coals, and a large amount of water is generally present.

Brown coal is not found in the strata of the true carboniferous system, but in the Tertiary, Cretaceous, and Oolitic rocks. It is in fact the name given to all coals which occur in formations more recent than the Carboniferous period.

Question 164.—What is a dynamometer? Sketch and describe it, and explain the method of its application for ascertaining the power given out by a prime mover. The power of a portable engine is tested by passing a strap or belt over the fly-wheel, which is 6 feet in diameter; one end of the belt is secured to a spring balance, and a weight of 200 lbs. hangs on the other end. What is the horse-power of the engine when the balance registers a tension of 100 lbs., and the fly-wheel makes 220 revolutions per minute?

A dynamometer is a measurer of power.

It is often of great importance to know the amount of work done by a prime mover over and above that which is required to overcome the friction of its parts.

The dynamometer is employed for this purpose.

In the case of a steam-engine, by means of the indicator, the total amount of work performed is ascertained, and if that shown by the dynamometer be deducted from the total indicated work, the balance represents the amount of work absorbed by friction among the moving parts of the engine itself.

Fig. 472 shows a common form of dynamometer as applied to the steam-engine.

It consists of a friction-brake, A, loaded at one end by weights, B, to a known amount.

At the other end of the lever a steel band, C, is fixed. This band may be tightened or slackened by means of the nut D working on the screw attached to the end of the band. The appliance is placed on some attachment to the main shaft, such as the fly-wheel of the engine to be tested, or a pulley. This is done by placing blocks of wood, E E, between the lever and the engine-pulley, F, and also between the steel band and engine-pulley. After the engine is started, the nut D is turned until the blocks E E bear upon the engine-pulley F with sufficient force to cause such friction between the blocks and the periphery of the wheel that the weighted lever will be lifted and float between the stops G G. The purpose of the stops, which are securely fixed, is to prevent the weighted

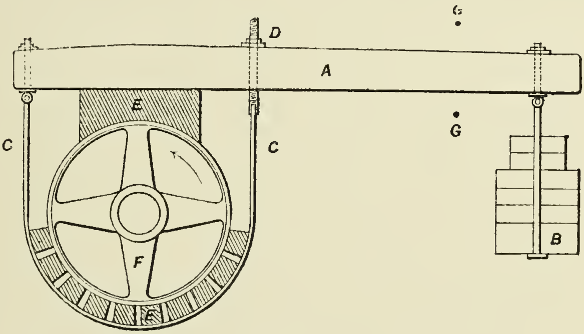


Fig. 472.—Sketch of a Dynamometer.

lever from being carried round with the wheel, or dropped down in the other direction. In adjusting the weights B, they must be varied, until the flotation of the lever is accurately effected. When the blocks, lever, and weights are thus supported by the revolving engine-pulley, it is considered that at any and every instant of the period of flotation, they are in one with that pulley, and are being turned about its centre.

If, now, the weight of the whole appliance and the position of its centre of gravity be known, there is, in effect, a weight which is being continuously lifted by the arm of an imaginary wheel, whose radius is the distance (measured perpendicular to the line of pull of gravity) of the centre of gravity of the apparatus from the centre of the main shaft. The work done by the engine in H. P. =

$$\frac{\text{Weight of whole apparatus} \times \text{circum. of imaginary wheel} \times \text{revs. p. min.}}{33{,}000}$$

Referring to the second part of the question, the weight being 200 lbs., we have 200 − 100 shown on the balance = 100 lbs., the downward pull, which is balanced by the revolving fly-wheel. The work done then is

$$\frac{100 \times 6 \times 3{\cdot}1416 \times 220}{33{,}000} = 12{\cdot}5664 \text{ H. P.}$$

Another form of dynamometer is often used on underground engine planes. It may be used on the empty or on the full tramway, on the main, or on any branch road. Used in this way it indicates the tractive power required to work

either the main road, or branch roads, separately, or together. The readings are usually noted at different points on the plane. The dynamometer is attached to the chain or rope for the purpose of making the observations.

Question 165.—What are the most important elements which enter largely into the major portion of the rock masses to which we have access?

The most important elements are :—Aluminum, calcium, carbon, oxygen, and silicon.

Question 166.—What is the difference between a mineral and a rock?

A mineral is composed of a single element, or a compound of two or more elements occurring native. A rock is a mixture of minerals.

Question 167.—Write down in order a scale of hardness of "rock masses," taking Talc as 1.

Beginning with the softest, 1, Talc; 2, Gypsum; 3, Calc spar; 4, Fluor spar; 5, Apatite spar; 6, Felspar; 7, Quartz; 8, Topaz; 9, Corundum; 10, Diamond.

Question 168.—With what other minerals is coal usually associated?

Coal is usually associated with beds and nodules of ironstone, sandstone, gannister or fire-clay, iron pyrites, &c.

Question 169.—In what rock formations are the following minerals found in the British Isles?
(1) Coal beds; (2) Salt; (3) Lead; (4) Iron.

The principal formations are (1) Carboniferous beds; (2) Trias beds; (3) Carboniferous limestone and silurian schists; (4) Lias, carboniferous and silurian beds. Inferior coals are found in several formations, but these coals are not of a true order of beds, as the carbon period.

Question 170.—What are beds and veins of minerals, and how do they differ?

Veins are fissures in the earth's crust carrying metallic ores; beds are layers of mineral matter lying conformable to the stratification.

Question 171.—Explain the difference of a vein, a "true fissure" vein, and a lode.

An ordinary vein is a fracture or fissure containing metallic ores; a true fissure vein is a vertical mass of metallic ores, of indefinite depth and longitudinal extension, but of a definite thickness; and a lode is a wall of mixed minerals enclosed in a fissure dipping at angles between the vertical and 70°, intersecting the successive rock masses with which it comes in contact.

APPENDIX.

REPORT OF THE ROYAL COMMISSION ON ACCIDENTS IN MINES.

In concluding their Final Report (dated 15th March, 1886), Her Majesty's Commissioners appointed to inquire into Accidents in Mines gave a Summary of the most important subjects which had been dealt with in their several Reports, and of the chief conclusions and recommendations which they had adopted.

The Commissioners were the late Sir Warington W. Smyth (Chairman); the Earl of Crawford and Balcarres; Sir George Elliot, Bart., M.P.; Sir Frederick Abel, F.R.S.; Professor Tyndall, F.R.S.; Mr. Thomas Burt, M.P.; Professor R. B. Clifton; Sir W. T. Lewis; and Mr. Lindsay Wood, M.P.

The Commissioners' Summary is as follows:—

Ventilation.

Volumes of air sufficient for the ventilation of even the most extensive collieries are capable of being passed through the workings by means of properly constructed furnaces, or by mechanical contrivances, such as are already in action at most of the collieries.

At a large number of collieries the sectional area of the intake and return-air-courses may be increased with advantage.

Where furnaces are used, they should by preference be in connexion with dry and deep shafts, and should be provided with dumb drifts.

Where mechanical contrivances are employed, they should be in such positions and placed under such conditions as will tend to insure their being uninjured by an explosion, and, if they are not provided altogether in duplicate, there should be at least an engine in reserve.

The improved system of ventilation by "splits" and the shortening of the air-courses, as practised in the larger collieries, is a subject of great importance, and we recommend that more general attention should be given to it.

It would conduce greatly to safety if the system of carrying the intake air through two parallel drifts, of which one may be used as the travelling road, were introduced into workings likely to become extensive, and where mechanical haulage is intended to be employed.

Fall of Roof and Sides.

That the casualties due to falls of the roof and sides are much more numerous than those due to any other causes is demonstrated by the tabular statement given at the commencement of this report. It is essential that all the officials and

workmen in mines should pay special attention to the careful propping of the working places and travelling roads.

In the North of England the system of trusting mainly to officials (deputies) for the timbering, is found to answer well; in South Wales and other districts, where the roof, face and sides are more liable to falls, the system of the men timbering their own working places has been found to be best.

We are of opinion, however, that in all cases the security of the working places should be examined into by over-lookers once at least in the course of each shift.

Supervision has been greatly enlarged in the last 35 years, and we find that there is generally one official so employed to about 20 men, sometimes one even to 11 or 12 men.

In order to reduce the number of casualties from falls, we recommend the observance of the following:—

A. The maintenance of ample supplies of timber in localities convenient to the workmen.
B. The proper training of each miner to the best modes of timbering and of otherwise protecting his working place.
C. The exercise of increased care on the part of the workmen in watching the roof, sides and face, and protecting themselves in time.
D. The introduction, as far as possible, of arrangements with the workmen, which will make it their interest not to avoid the labour of putting up the necessary timber, cog walls, buildings, or cogs for their proper protection.
E. The employment of special timbermen or deputies for the timbering of main-ways and also for the repairing as well as drawing of timber.
F. Preventing timber being left in the goaf of long wall workings, which would have the effect of breaking the roof.
G. Driving the working places as rapidly as possible by shifts of an ample number of workmen in each face, and so reducing the risk of falls and exposing the least number of men to danger at any one time.

Miscellaneous Accidents.

We are of opinion that by improved discipline and the exercise of greater care by those employed in or travelling through engine planes and other roadways, the number of casualties comprised under the head of "miscellaneous accidents," would be considerably diminished. The practice in some collieries in South Wales of boys running in front of the horses and trams should be prohibited.

The very numerous casualties under the heads of "falls of roof and sides" and "miscellaneous accidents," are due in great part either to carelessness or want of early training. Looking to the importance of practical training and of encouraging boys to enter the mines at the ages specified by the Mines Regulation Act, we are of opinion that careful consideration should be given to this point in connexion with the administration of the Elementary Education Act.

Firedamp.

We think that the experiments we have made on the pressure of fire-damp in plugged bore holes, in coal, a pressure sometimes amounting to upwards of 400 pounds on the square inch, have thrown much light upon the occurrence of sudden outbursts of gas. The boring of holes upward or downward has been successfully tried as a means of avoiding such outbursts, and we have little doubt

that the closer attention which is now paid to thorough stowing and packing or building in the workings will contribute greatly to the same end.

It is almost impossible to account for many of the accidents which have occurred in well managed mines, some of which have originated in the main-intake airways, except upon the supposition that gas has suddenly invaded the workings from the adjacent strata. Sudden outbursts of large quantities of gas, accompanied by violent disruption of the floor, roof, or coal, are fortunately rare, but smaller incursions of gas, accompanied by falls of roof, or even without any apparent displacement of ground, are comparatively frequent.

We are of opinion that in working fiery seams at great depths such abnormal discharges of gas must occasionally occur, yet that they may be successfully met by ample ventilation, good discipline and efficient lamps.

While we recognise that variations of atmospheric pressure exert an influence on the escape of gases which have accumulated in cavities, and possibly to a slight extent on that of gases emitted directly from the coal, we entertain great doubt as to the wisdom of placing reliance on the issue of meteorological warnings. These can at best only convey very imperfect information, which, moreover, may be sometimes dangerously misleading. We are of opinion that safety would be much more likely to be ensured by unceasing vigilance on the part of the officials and workmen in the mine than by any attention to such warnings.

Coal Dust and its Relation to Explosions.

The action and effects of coal-dust in connexion with mine explosions have been made the subject of careful study and comprehensive experiment by numerous workers since attention was first drawn, about 42 years ago, by Faraday and Lyell, to the functions exercised by coal-dust in "aggravating and extending the injurious effects of fire-damp explosions." The results and conclusions which have been arrived at in this direction, and to which the labours of your Commissioners have contributed, are sufficiently complete and definite to warrant the following authoritative statements:—

The disastrous effects of fire-damp explosions in coal-mines are almost always aggravated and extended by the existence of coal-dust in *dry* mine-workings and roadways.

A gas explosion in a *dry* mine, even if only of comparatively trifling nature, will raise and inflame coal-dust existing at the seat of the explosion or in the vicinity; the flame attending the explosion will be thereby increased and carried to more or less considerable distances, and may thus become communicated to any accumulations of explosive gas-mixture which may exist in goaves or other lurking-places at a distance from the seat of the original gas explosion.

The firing of an explosive in a shot-hole of a strength which is in excess of the power applied, or which has not been sufficiently tamped, will result in the almost complete projection of the highly heated products of explosion and of a more or less considerable body of flame from the mouth of the hole, as from the bore of a gun; it thus produces what is known as a *blown-out shot*. And further, if the charge of explosive is decidedly greater than that necessary to perform the desired work in the coal or stone where it is applied, a more or less considerable projection of highly heated products of explosion will also take place, and effects similar to those of a blown-out shot will be produced.

The production of a blown-out *powder* shot in a mine working, *in the entire absence of coal-dust*, or in a wet mine is not attended by the projection of flame to a very considerable distance, but the flame thus projected is much increased in volume if, as is frequently the practice, dry or slightly damp small coal has been used as stemming for the shot.

If a blown-out *powder*-shot be produced in a *dry* locality where coal-dust exists in more or less abundance, the flame, projected by the shot, is sure to be considerably increased and extended by the ignition of portions of the dust-cloud which is raised by the rush of air occasioned by the firing of the shot. A result of this nature will be produced even if the air in the vicinity of the blown-out shot is entirely free from fire-damp.

Unless the coal-dust which exists in the immediate vicinity of a blown-out *powder*-shot is dry, very finely-divided and of a very highly inflammable character, the propagation of flame from the shot by the raised dust will only take place to a comparatively limited extent if the atmosphere in which the dust is raised be entirely free from fire-damp.

It is, however, well established that even when the air is quite free from fire-damp, an exceptionally inflammable coal-dust, in a very finely-divided and dry condition, and existing in abundance in the immediate vicinity of a blown-out shot, may, when raised by the shot, be ignited so readily, and carry on the flame so rapidly, that it may produce explosive effects of a similar character to those caused by a gas explosion. The flame as it rushes along, if fed by freshly raised dust, may extend under these circumstances to very considerable distances, with results resembling in their disastrous nature, those of explosions originating with, and mainly due to, fire-damp.

If a blown-out *powder*-shot occurs in a locality where the atmosphere contains a small proportion of fire-damp (even not above two parts in 100 of the air), the presence of dry, fine, and porous dust, even if it be only comparatively slightly inflammable, may give rise to the explosive propagation of flame to distant localities where either accumulations of inflammable or explosive gas-mixture (as in goaves or old working places), or deposits of very inflammable dust, may take up the explosion and still further extend its disastrous effects.

Wherever a coal is worked which contains inflammable gas, the atmosphere in the vicinity of the workings, however efficient the ventilating arrangements, will at one time or another, and it may even be said generally, contain some small proportion of fire-damp.

Mines have hitherto been considered free from fire-damp when the search for gas by means of a lamp flame has been unattended by the appearance of a cap upon the flame or by an elongation of the flame. This test, however, fails to indicate the presence of fire-damp, if the atmosphere contains less than from 2 to 2·5 per cent. of its volume of marsh gas.

Such a slight contamination of the atmosphere by fire-damp is not only sufficient to greatly enhance the dangers due to the existence of dust in any abundance in a dry mine-working, as already described, but is also sufficient actually to give rise to the production of an explosive mixture with dust raised in it by a blown-out shot.

Small proportions of gas, such as are referred to, when existing in the atmosphere of a mine, can now be detected, by more delicate gas-indicators than a lamp flame; but, while a knowledge is thus afforded of the presence of gas, it remains impracticable to prevent such slight contamination by fire-damp of the air of a mine near the working places.

Shot Firing.

It will be seen from the foregoing that such contamination, although quite insufficient to constitute in itself a source of danger, does become dangerous if dust co-exists with it, in abundance, in dry mine-workings, if *powder*-shots are fired in such workings.

No means are at present known by which security can be attained against

blown-out shots during blasting in hard coal or in stone, and the use of powder in coal is sometimes attended by the emission of flame, even when blown-out shots are not produced.

It follows from the foregoing that the firing of *powder*-shots in a *dry* mine-working where dust exists in abundance must always be liable to be attended with disastrous results if the air in such a locality is contaminated by fire-damp, even to so small an extent as in the proportion of 2 volumes in 100 volumes of the air of the mine.

The constant removal of accumulating dust from the workings in *dry* mines, to such an extent as to guard against the raising of any considerable quantity of dust where shots are fired, could scarcely be so thoroughly carried out, in any but very exceptional cases, as to constitute by itself an effectual precaution.

The application of water to the laying of dust in roadways has been applied here and there with some amount of success, but the effective adoption of such a measure in or near the working places is in some instances attended with practical difficulties.

Unless very copious watering be resorted to, it would be ineffectual in guarding against the dangers arising from the firing of *powder*-shots in *dry* and dusty workings where the air may contain some small proportion of fire-damp. The employment of hygroscopic or deliquescent salts in conjunction with water has not been found a trustworthy means of maintaining dust in a safely moist condition.

The dangers which attend the firing of *powder*-shots in *dry* mine-workings where dust exists in abundance, and where the air may contain even only a small proportion of fire-damp, can not therefore, with our existing knowledge, be effectually guarded against, except by combining the removal of dust as far as practicable with very copious watering.

The obvious inference to be drawn from the foregoing is that a due regard for the safety of those employed in mines, *where the conditions above indicated prevail,* precludes the use of powder, *unless the precautions just specified are effectually applied.*

Means of Safely Working without Powder.

The results of extensive practical experiments, carried out by ourselves and by others, have demonstrated that the abolition of the use of powder, where the conditions above indicated prevail, will not generally involve any formidable inconvenience, because the work which is accomplished by its employment, both in coal and in stone, can now be performed with equal efficiency and at very little, if any, greater outlay, by one or other of the following available alternative means :—

(*a.*) In some coal-seams the lime-cartridge will perform work quite equal to that accomplished with powder, at no greater cost, and with absolute immunity from risk of explosions.

(*b.*) Mechanical appliances exist which will do efficient work, not only in some kinds of coal, but also in some stone or shale over- or under-lying coal.

(*c.*) The so-called "high" or violent explosive agents, which are represented by dynamite or gelatine-dynamite, and by gun-cotton or tonite, can now be applied, not only for working economically in stone or shale, but also for coal-getting, by using them in conjunction with water, according to one or other of the methods described in this Report.

The "high" explosives may be used, as indicated in *c*, with security against the ignition of coal-dust, thickly suspended in air, by a blown-out shot or by the effects of an over-charged hole, even when the air contains some small proportion of fire-damp.

One very simple method of using the "high" explosives in conjunction with

water, included in *c*, which may be supplemented by the use of ordinary tamping for securing the best working results, has, so far as several severe tests have shown, afforded a complete safeguard even against the ignition of an explosive mixture of fire-damp and air by a blown-out shot.

Therefore, in *dry* mine workings, where the removal of dust combined with copious watering cannot be carried out, and where neither of the alternative methods, *a* and *b*, of working in coal or stone can be advantageously substituted for blasting by means of powder, in localities where fire-damp is liable to have access to the mine-workings, shot-firing may be safely carried on, provided that any one of the "high" or violent explosives is employed, in one or other of the modes described, in substitution for powder.

But the methods of operation which furnish effective safeguards when applied in conjunction with the "high" explosives, fail to furnish such safeguard when applied in the same way, together with *powder*.

Unless, therefore, effective measures be adopted for the removal of dust, as completely as practicable, in the vicinity of the place where the shot is to be fired, such removal being followed by copious watering, the employment of powder, or of any explosive preparation of a similar nature to powder, should be prohibited in dry coal-mines where fire-damp may pervade the air, and where at the same time coal-dust accumulations are unavoidable.

Precautions to be Observed with Blasting.

With the view of promoting security from accidents under circumstances where blasting may be practised in coal-mines, we would recommend that the following instructions be observed :—

1. That all work involving blasting in mines should be entrusted only to experienced workmen.
2. That in order to lessen the risk from blown-out shots, particular care should be taken that each shot should be assisted by under-cutting and nicking or shearing whenever it is practicable.
3. That the tamping, stemming, or ramming should consist of very damp or non-inflammable material.
4. That where strong tamping is needed, the compression of air at the bottom of the hole should be avoided by pushing in the first part of the tamping in small portions.
5. That where safety lamps are used, and powder is employed, the shots should be fired only by specially appointed shot-men, who before firing the shots shall satisfy themselves that the foregoing instructions are observed, and shall also satisfy themselves, by carefully examining all accessible contiguous places within a radius of 20 yards of the shots to be fired, that fire-damp does not exist to a dangerous extent.

Precautions in Firing Shots.

The employment of the ordinary miner's fuze, which, when burning, is liable to allow fire to escape from its extremity or laterally into the atmosphere, should not be permitted in any mine-workings where the exigencies of safety dictate the exclusion of powder and the substitution, for it, of one or other of the "high" explosives in conjunction with water.

Similarly, no description of mining fuze, however safe in itself, should be allowed to be ignited in such localities, by means either of a lamp-flame, or of a wire which has been made red-hot by inserting it into the gauze of a safety-lamp, or by means of any other source of fire, which when applied to the lighting of the fuze, must come into contact with the atmosphere of the mine.

Use of Electricity for Firing.

Electrical exploding appliances present very important advantages from the point of view of safety, over any kind of fuze which has to be ignited by the application of flame to its exposed extremity, as the firing of shots by their means is not only accomplished out of contact with air, but is also under most complete control up to the moment of firing. Their simplicity and certainty of action have been much increased of late years, while their cost has been greatly reduced, and but little instruction is now needed to ensure their efficient employment by persons of average intelligence.

For the foregoing reasons the use of electrical arrangements for firing shots in mines, where the employment of powder for blasting is inadmissible, should be encouraged as much as possible.

Where the regular use of electrical exploding appliances is attended with serious difficulties, as in wet mines, a special form of miner's fuze now procurable at a cost very slightly, if at all, greater than that of the ordinary miner's fuze, and exempt from the defect of a possible lateral escape of fire, should be employed, but it should be used only in conjunction with a special self-contained igniting arrangement. Such an appliance should be constructed to fit over the entire exposed end of the fuze in a shot-hole, and to ignite the fuze out of contact with air, and after the lapse of a definite interval (*i.e.* 5 minutes), from the time when it has been set into action by the person in charge of the shot-firing. Simple, cheap, and efficient forms of "igniter" have been devised, which fulfil these conditions.

Safety Lamps and Open Lights.

It has been shown that mines which have hitherto been considered free from fire-damp may have the air which passes through them vitiated to an extent corresponding to about 2 per cent. of its volume of marsh gas. The air in many such mines may probably never be entirely free from explosive gas, at all events in the neighbourhood of freshly cut faces of coal and in the return air-ways.

It has been demonstrated in our experiments that when the atmosphere contains 5 to 5·5 per cent. of marsh gas it becomes highly explosive. We have even obtained explosions which, though less violent, might be nevertheless destructive of life if they occurred on the large scale possible in a mine, when the air contained only 4 per cent. of marsh gas.

It will thus be seen that air which would appear free from gas if tested in the ordinary way, may become by the addition of only about 2 per cent. of marsh gas, capable of propagating flame and causing destruction, while the addition of about 3 per cent. converts it into a highly explosive mixture.

As we have already pointed out, air which would appear quite free from gas if examined by a lamp-flame may become explosive when laden with fine, dry coal dust.

It has been stated that appliances now exist by which very small proportions of marsh gas in air may be readily detected, and which can be used for examining the atmosphere of a mine. With Liveing's indicator, gas present in the air can be estimated with sufficient accuracy for all practical purposes, even when the proportion is as low as 0·25 per cent. Maurice's indicator is also capable of giving accurate measures of the proportion of gas, and is very portable, but the time required in taking an observation with the instrument in its present form seems to preclude its practical application.

The natural inference from the foregoing is that some mines hitherto considered safe with naked lights may at times be in peril.

It may be that risks of explosion, arising out of the possibility of an unforeseen contamination of the air by fire-damp to a dangerous extent in parts of the working of some coal mines, can only be provided against by the invariable use of safety-lamps. We have not, however, considered it advisable to make a suggestion of this nature, because the great preponderance of casualties due to falls of stone and coal, over those arising from explosions, points to the importance of miners having the advantage of the superior illumination afforded by naked lights in comparison with even the best forms of safety-lamp, when the circumstances of the mine, in regard to association of fire-damp and coal dust, do not necessitate the use of safety-lamps.

Inspection with Gas Indicators.

We have therefore arrived at the following conclusions:—

1. That it is most important that all mines should be carefully examined by means of indicators capable of detecting as small a proportion as 1 per cent. of gas; such examination to be made before the commencement of each day-shift, and, in case of an interval, also before the succeeding shift.

2. That in all *dry* mines where the air may be laden with coal dust, and where fire-damp is either known to be given off from the strata or may from experience be reasonably suspected to exist, the Secretary of State may require safety-lamps to be used, unless the owners and workmen of such mines prove, to the satisfaction of a court of arbitration to be appointed by the respective parties, that less liability to accident, generally, will be involved by the working of the mine with open lights than by the use of safety-lamps. It should be a special instruction to such court that the circumstances of each mine be taken into consideration with reference to the following points:

(*a.*) The mode of working.
(*b.*) The nature of the coal seams and of the roofs and floors of the seams and of the adjacent strata.
(*c.*) The proximity of the seams to each other.
(*d.*) The emission of gas from the seam, and the liability to blowers or outbursts of gas from the coal, roof, or floor.
(*e.*) The order of working the seams of coal.

Mixed Lights.

For the system which prevails in some places of working with mixed lights, that is, with open lights and safety-lamps intermixed in the same set of workings, there is no justification, and this practice should be strictly prohibited.

We are of opinion that, in mines where safety-lamps are required, the position of lamp stations, or places where open lights are allowed, in reference to the possibility of access of vitiated air, should receive much more attention than at present. It is desirable that, at convenient places near the working faces, reserves of lighted and locked lamps be kept available for exchange with those extinguished in the workings.

Safety Lamps.

It has long been known that if the atmosphere become inflammable the Davy and Clanny lamps, and in a less degree the Stephenson lamp, are unsafe in currents having velocities much below those encountered in well ventilated mines. Our experiments fully confirm this. The ordinary Davy lamp becomes unsafe before a velocity of 400 feet per minute is attained. The ordinary Clanny lamp will almost certainly cause an explosion in a current having a velocity of 600

feet per minute. A Stephenson lamp will frequently cause an explosion in a current with a velocity of 800 feet per minute.

From the information supplied to us by your Majesty's Inspectors of Mines and others, currents having velocities of more than 400 feet per minute are now frequently found in working places. The currents sweeping long wall faces have very often higher velocities, in main air-ways current-velocities approaching 2,000 feet per minute are recorded, and considerably higher velocities are encountered at regulators and in narrow places or when large falls occur.

It is thus obvious that, in the present improved ventilation of collieries, ordinary Davy and Clanny lamps have ceased to afford protection from explosion, and that the Stephenson lamp, though more secure than the two former, cannot be relied upon.

We felt it our duty at an early stage of our investigation to draw the attention of the Secretary of State to the danger attending the use of ordinary Davy and Clanny lamps, and our subsequent experiments have made this danger still more conspicuous. We have no hesitation in stating that these lamps should be prohibited, unless they are enclosed in cases capable of effectually preventing the gauze from being exposed to the full force of the current of air.

Many lamps now exist which are able to resist, in highly explosive atmospheres, current velocities up to and even exceeding 3,000 feet per minute, at all events for several minutes. Ample time is thus obtained for bringing into operation a "shut-off" appliance for the extinction of flame produced both by the illuminant or by ignited gas within the lamp.

We consider that all safety-lamps should be provided with such an appliance.

Lamps which have given the Best Results.

Four lamps seem to us deserving of special attention, as combining a high degree of security with a fair illuminating power and simplicity of construction. They are Gray's lamp, Marsaut's lamp, the bonneted Muescler lamp, and Evan Thomas's modification of the bonneted Clanny lamp, described as No. 7 in our Report. In our experiments the last lamp has given upon the whole the best results.

It will be seen, however, from our experiments that many other lamps exist which are simple in construction, and almost, if not quite, as safe as the above. They generally, however, yield an inferior light in consequence of the flame being surrounded by gauze, but from this method of construction they derive the advantage of not being entirely dependent on glass for their security.

Only Authorised Lamps should be Used.

To make a particular lamp compulsory would be unwise, as calculated to throw difficulties in the way of introducing improvements which will no doubt arise in the future, but we think it desirable that some control should be exercised in reference to the descriptions of lamps employed in coal mines, and that only those lamps should be used which are authorised from time to time by the Secretary of State.

A lamp may be of the safest pattern and yet small defects in the fitting of its parts may entirely deprive it of its power of affording protection. In preparing a large number of lamps for use in a mine it may happen, even with the greatest care on the part of the lamp-men, that a lamp in an imperfect condition may be allowed to pass. The detection of these imperfections by simple inspection is in many cases almost impossible, and we are convinced that the only way of avoiding the introduction into a mine of a dangerously imperfect lamp is to test every

lamp in an explosive mixture of air and some inflammable gas before it is allowed to descend the shaft.

Though we have good reason to believe that the practice of surreptitiously opening safety-lamps in the workings is much less prevalent than formerly, it is still necessary that such lamps should be locked. We have examined many appliances for this purpose, and we consider that the plan of fastening the oil vessel to the other part of the lamp by a riveted lead plug, impressed at each end with marks or letters varied from time to time is the simplest, the most efficient, and the one most likely to lead to the detection of any attempt to tamper with the lock.

The power and uniformity of illumination given by a lamp can be notably improved by using, as the illuminant, vegetable or animal oil mixed with about one-half of its volume of a petroleum oil of safe flashing point.

Danger of Volatile Illuminants.

The use of petroleum spirit or benzene as the illuminant in safety-lamps, instead of vegetable or animal oil, is attended with some advantages, but it is also liable to introduce new sources of danger. Special care is needed in the filling and trimming of lamps, and in the arrangement of lamp-rooms, to avoid the ignition of the highly explosive mixture formed by air with the vapour arising from this spirit.

The selling of petroleum spirit, or of spirit of similar character as to volatility, under designations which are calculated to mislead in regard to the nature of the illuminant, is a proceeding fraught with danger, unless all vessels containing such illuminants bear a prominent label, indicating the dangerous nature of their contents.

Stringent regulations as to the conditions under which illuminants of this class are to be used and stored, are absolutely necessary.

Electric Lighting.

The advantages in point of convenience and efficiency which attend the employment of electric glow-lamps for illuminating the pit's bottom, and roadways immediately adjacent to it, have already been demonstrated at several collieries, where this utilisation of the electric light has been combined with illumination at the surface by arc-lights.

In applying electric glow-lamps to underground illumination, to the extent indicated, through the medium of conducting cables leading from the generators to the pit bottom, it is essential to safety, as well as to the permanent efficiency of the installation, that the cables should be placed in positions where they are thoroughly protected against possible accidental injury. It is also essential, in all mines where fire-damp has been known to occur, that the glow-lamps should be excluded from direct contact with the air of the mine, in one or other of the ways indicated in this Report.

Portable, self-contained electric lamps have been devised, which will furnish, for several successive hours, a light considerably superior to that of the best safety-lamps, and which at the expiration of eight hours and upwards will still give a light fully equal to that of a freshly lighted Davy lamp. These lamps are perfectly safe, but, as they do not afford any indication of the condition of the atmosphere in a mine, their employment, even if special fire-damp detectors are used, cannot in any case entirely dispense with the necessity for the use of some safety-lamps.

For exploring purposes after accidents, or in foul places, these lamps must

prove very valuable even in the present condition of their development, and as auxiliary lights they cannot fail to prove very useful. The great progress which has recently been made in the construction of portable electric lamps affords promise of a speedy utilisation of such lamps to an important extent in coal mines.

Over-winding.

Whilst we think that the safety-hooks at present available may have contributed to prevent fatalities from over-winding, we believe that the best appliance for the purpose is an automatic steam brake attached to the winding-gear, and we think it desirable that such brake should be introduced where practicable.

Measures for Dealing with Casualties.

We consider that measures should be adopted to deal more systematically, and if possible more expeditiously, with casualties resulting from the various sources of accidents dealt with in this Report.

Collieries or mines should be required to provide an ambulance and stretchers for the purpose of conveying to their homes sufferers from injuries received while in the discharge of their duties.

Arrangements should be made for the establishment of centres in mining districts, where additional appliances for succour and relief, and also special appliances for exploring purposes, should be maintained in an efficient condition, so as to be ready for use at the shortest notice.

It is most desirable that facilities should be afforded for the instruction of men in the use of special auxiliary appliances for exploring purposes, and in simple measures connected with the provisional treatment of injuries.

Systematic Inspection by Workmen.

We attach great importance to the systematic inspection of each mine by the workmen, as provided for in General Rule 30 of the Coal Mines' Regulation Act, 1872, and we recommend that this provision should be generally and regularly acted upon.

Concluding Observations.

In submitting to your Majesty the results of our inquiries and experimental work, and the conclusions to which they have led us, we desire to express our regret at the unavoidable delay which has occurred in the presentation of our Report. This delay has been due to the wide range of important and very extensive subjects included in the reference to us, and to the great difficulties we have experienced in bringing to a close the experimental work upon which we have been engaged, almost continuously, since we first entered upon the inquiry entrusted to us.

These difficulties have arisen in part out of the constant succession of inventions and suggestions submitted to us in connexion with the questions under investigation, many of which demanded careful consideration and necessitated the institution of fresh experiments. They have also been in part due to the circumstance that, as our investigations progressed, the results obtained opened up new fields into which it was necessary to extend our inquiries.

In bringing our labours to a termination, we feel very strongly that many of the subjects with which we have dealt need much further elucidation by per

severance in experimental research of the kind which we have pursued. We are convinced that, if the work which we are relinquishing were continued, the knowledge of the conditions to be fulfilled for securing safety from preventible disasters, and the development of resources and appliances calculated to promote the fulfilment of those conditions, could still be much advanced.

It is moreover certain that new subjects for inquiry connected with the safe working of coal-mines must continue to present themselves, as has been the case during our seven years' experience. These considerations have impressed upon us the need for the official establishment of some permanent arrangement, by which the continuous pursuit of this highly important class of work would be secured, and by which, also, the merits of suggestions and inventions presenting themselves from time to time would be investigated promptly and thoroughly, and dealt with authoritatively.

We consider, moreover, that the complete investigation of coal-mine disasters would be greatly promoted if the arrangements to which we have referred were utilised systematically, in connection with the usual official inquiries, in dealing with the difficulties which frequently arise in elucidating the causes of these disasters.

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THE END.

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